JUNE, 1961

Welding Journal

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Pressure Vessel Analysis of Submarine Hulls, by Edward Wenk, Jr. 272-s

Published for the advancement of the science and art of welding by the American Welding Society

Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices, 33 West 39th St., New York 18, N. Y. Subscription $8.00 per year in the United States and possessions; foreign countries $10.00. Single copies, nonmembers $1.50; members $1.00. Second-class privileges authorized at Easton, Pa. This publication is authorized to be mailed at the special rates of postage prescribed by Section 132.122. Copyright 1961, by the American Welding Society. The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication provided credit is given.

PRESS-TIME NEWS

...about
...People
...Welding
...Products

New Honors for Biers

The election of Dr. Howard Biers [illegible], of New York, internationally distinguished metallurgist and consulting engineer, as an honorary vice-president of The Iron and Steel Institute, London, was announced in New York coincidentally with this designation by the American Institute of Mining, Metallurgical and Petroleum Engineers as its representative at the Annual General Meeting of the British organization May 3–4, 1961.

Dr. Biers, who is a consultant to the Union Carbide International Co., is a past president of the International Institute of Welding. He is also an honorary life member of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME) and has been an honorary member of the British organization since 1955.

European Welding Experts Visit U. S. Welding Plant

European educators, industrialists and government officials were among guests of Eutectic Welding Alloys Corp. for a tour of its expanded facilities in Flushing, L. I. From left are Adolph Luthy, Switzerland; Professor, Walter Soete, Belgium; Jan Boumeester, The Netherlands; Johannes Schatz, Germany; Leo Laursen, Denmark; Paul Steidl, Germany; Helmut Scheumann, Germany; and J. F. Quaas, Eutectic vice president. The guests were delegates to the International Institute of Welding which met in New York April 10–15 and later attended meetings of the AMERICAN WELDING SOCIETY April 17–21.

NEMA Western Conference

Chris J. Witting, Pittsburgh, Pa., vice president of Westinghouse Electric Corp., will keynote the Western Conference of the National Electrical Manufacturers Association with an address at the opening luncheon meeting, June 8th, at The Biltmore Hotel, Los Angeles, Calif.

The June 8–9 Conference, first to be held west of Chicago by the nation's largest trade organization for electrical manufacturers, will be under the direction of Co-chairmen A. Arval Morris, Anaheim, Calif., president of Electra Motors, Inc., and Raymond M. Waggoner, Emeryville, Calif., vice president—West Coast—Hubbard and Co.

Metal & Thermit Declares Dividend

Directors of Metal & Thermit Corp., at their regular meeting, declared a dividend of 30 cents per share on the common stock.

The dividend is payable June 12, to shareholders of record at the close of business on June 2, 1961.

The directors also declared the regular quarterly dividend of $87\frac{1}{2}$ cents per share on the preferred stock, payable June 26, 1961.

E. H. Smith Receives IAA Award

Elmer H. Smith, founder and current Chairman of the Board of the Smith Welding Equipment Corp., Minneapolis, Minn., was named as recipient of the International Acetylene Association's James Turner Morehead Medal for 1961. Presentation of the medal, which is the IAA's highest award, was made to Mr. Smith at a banquet at the Sheraton Plaza Hotel in Boston on April 25th.

Mr. Smith, who celebrated his 50th year in the welding equipment business in 1959, is the holder of numerous patents in the welding field which include significant improvements in the design and function of both welding and cutting torches and tips. From 1937 to 1939, he served as president of the International Acetylene Association.

E. H. Smith

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This Hobart "Mainliner" gives you more for your money...
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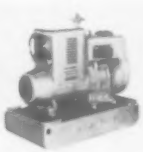

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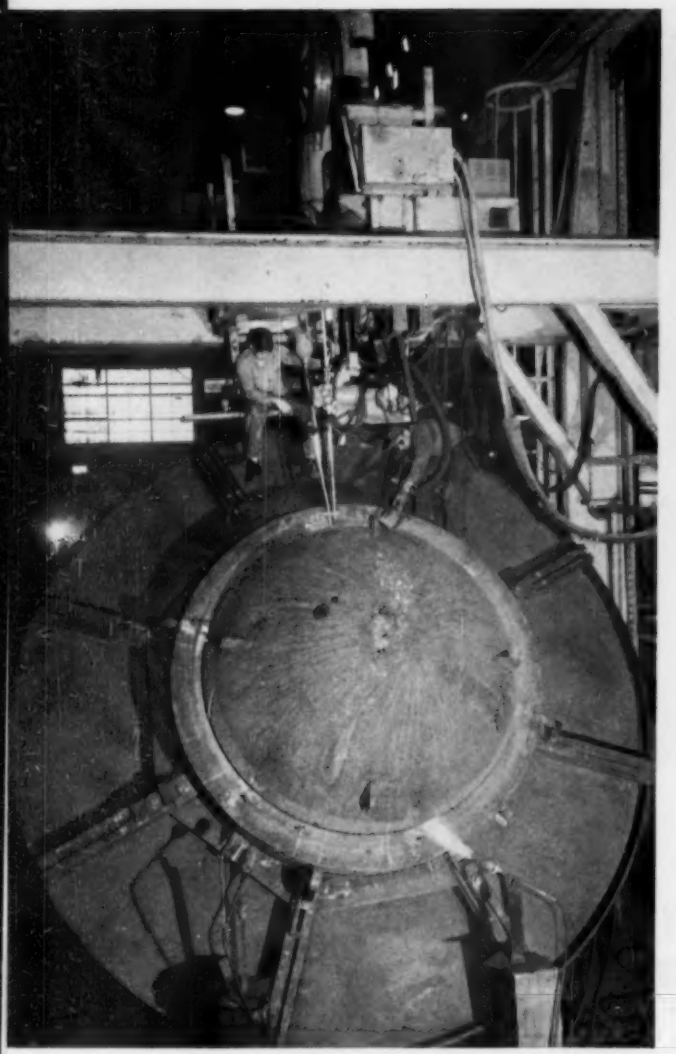
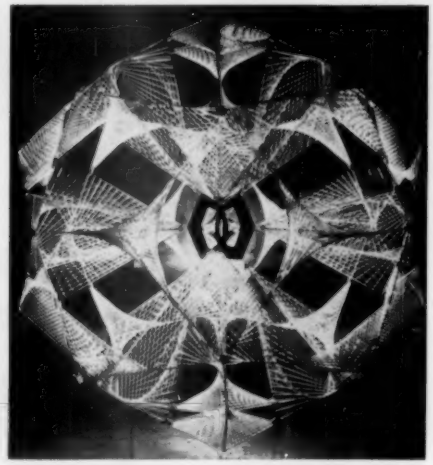
WELDING ZONES



Six-ton flange forging head for a nuclear reactor pressure vessel being submerged-arc welded to the 4-ton commercial A212 Grade B formed steel reactor head. (Courtesy Allis-Chalmers Manufacturing Co.)

Corrosion-resistant 465-lb wrought iron scupper measuring 2 ft, 1 in. in length and $1^{2}/_{3}$ ft in width fabricated by Tri-State Fabricating Co. (Courtesy A. M. Byers Co.)



"Astrosoma," a welded sculpture in space fashioned by Prof. Roy Gusson of the School of Design at North Carolina State College, Raleigh, N. C. (Courtesy Linde Co.)

Giant stainless steel storage tank used in the Missile Defense Program. It will be inserted into a conventional steel casing and insulated with perlite by Struthers Wells Corp. (Courtesy Allegheny Ludlum Steel Corp.)

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TIG welding solved a major problem in producing new, lightweight mining hopper cars. And whether you're welding railroad cars, transcontinental pipelines, or nuclear steam-supply valves, Tungsten Inert Gas Welding gives you many outstanding benefits. For the finest there is in Tungsten Electrodes, look to Sylvania.

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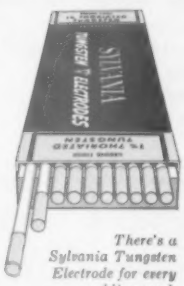

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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

CZECHOSLOVAKIA

Zvaranie for July 1960 contains the following articles:

1. Submerged arc and electroslag welding is important in spreading automation in accordance with the third five-year plan.

2. A nomogram is given for designing joints for capillary silver soldering and brazing, based on an article in *Welding Engineer* for June 1955.

3. The throat of resistance welders requires sufficient rigidity to prevent misalignment of the electrodes, yet without excessive weight. A graph shows the increase in angle of deflection of the electrode with increase in thickness of sheet to be welded.

Five articles on welding in the railroad industry are in the August issue. The thermit process is preferred for rail joints. The crankshafts of rail car engines are repaired by welding with 570° F preheat. Engine valves of steel containing 0.10 C, 1.4 Mn and 0.9 Si are hard surfaced with 0.23 C, 0.9 Mn, 1.4 Si and 3.5 Cr. Another paper advocates a covered electrode depositing weld metal containing 0.10 max C, 19 max Cr, 15 max Fe, 5W + Mo, 1.5 Ti, 0.8 Al, balance nickel for avoiding cracks in welding austenitic stainless steels. The application of waterglass in electrode coatings is the subject of another paper, special emphasis being placed on reaction between limestone and waterglass.

EAST GERMANY

The July 1960 issue of *Zis Mitteilungen*, from the Central Welding Institute of East Germany is devoted to thermit welding. In 1960 it was forecast that 240,000 railway rail joints would be thermit welded in East Germany. The total weight of rail welding equipment, including mold, pattern, mold welder, crucible and support is only 68 lb. Time per joint is 21.5 to 28.5 min. In 1959, 38 tons of thermit was used in East Germany to build up badly worn areas of large extent on dredges, aerial tramways and similar equipment. Hardnesses up to 550 Brinnell are attainable. Thermit also is used for welding concrete reinforcing bars and for joining stranded aluminum electrical cable. Bend fatigue results on thermit welded rail containing 0.43 C, 0.90 Mn and 0.15 Si met specifications. One specimen withstood 1,600,000 cycles of 50,000 psi upper stress, 7000 psi lower stress before fracture. The foot of the joint was in tension and only the head was machined.

The August 1960 issue reviews oxyacetylene technology. Tests on oxygen cutting showed the effects of the following factors on oxygen cutting of steel: (*a*) sulfur in acetylene and low oxygen purity; (*b*) optimum tip-to-work distance for maximum cutting speed; (*c*) six preheat holes versus ring preheat flame; (*d*) cylindrical and lapped oxygen orifices versus Zobel venturi type.

The six-hole tip is expected to replace the ring-shaped preheat flame in East Germany. A training course for cutting torch operators is in operation. Other articles described ways of economizing on acetylene, the design of acetylene generators, standardization of gas equipment and applications of flame hardening.

Schweisstechnik

The August 1960 issue of the East German magazine *Schweisstechnik* contains the following articles:

- A plea is made for specialization by East German manufacturers in producing welding machines, equipment and fluxes. East Germany is third in application of automatic welding in the world, yet the plants manufacturing submerged arc and inert gas equipment have their energies diverted into other channels, such as power supplies. The plea is for a coordinated plan of specialization and standardization.
- Tables and graphs are given for the application of fully automatic CO_2 welding to small fillets 0.04 to $^1/_8$-in. throat in repetitive work. CO_2 welding has the advantage over manual welding with covered electrodes, not so much in melting rate as in nonproductive time.
- Submerged arc fluxes in East Germany are of three general types: 60% is fused flux of which 90% comes from continuous furnaces; 35% is sintered flux usually containing finely divided active carbon and deoxidizers; the remaining 5% is bonded flux dried at 700 to 1800° F. Two plants produce flux. Piesteritz produces a low-cost continuous furnace product (45 SiO_2, 21 CaO, 6 MgO, 2 Al_2O_3, 18 MnO, 5 CaF_2) and a batch furnace flux (40 SiO_2, 42 MnO, 10 Al_2O_3, 2 CaF_2). The Weisswasser plant produces sintered flux (48 SiO_2, 18 MnO, 21 CaO, 6 MgO, 6 CaF_2; and 30 SiO_2, 15 MnO, 30 Al_2O_3, 2 CaF_2, remainder CaO + MgO).
- A production line incorporating rotating positioners is described for fabricating the trucks of 150-ton electric locomotives. Coped holes allow the submerged arc welding head to make continuous welds without stopping at stiffeners. The labor cost of a pound of submerged arc weld metal is computed as one half the labor cost of a pound of manual covered electrode weld metal. The latter is $0.83.
- The equipment for fully automatic submerged arc welding of tee and bulb sections at the Rostock shipyards consists in part of a fixed head with moving carriage for the work, and in part of squirt guns propelled by a carriage. The production time is made up 16% of preparation of webs and flanges, 76.5% of fit-up, tacking, and straightening after welding, and 7.5% of welding. A welded tee beam with $9^1/_2$-in. web costs $1.14 per foot.
- A flash welder is described for welding seamless tubing $1^1/_2$-in. OD, $^1/_8$-in. wall for feed water heater coils.
- Three single-purpose inert gas welding machines are described, one for welding strip, the second for aluminum containers for uranium and the third for compressor capsules made of $^1/_8$-in. sheet.
- The principles of statistical quality control in evaluating production welding are explained.
- A series of tensile tests were made on steel joints combining butt and

DR. GERARD E. CLAUSSEN is associated with Arcrods Corp., Sparrows Point, Md.

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fillet welds. If the throat area of the fillets is less than that of the butt joint, the safe design area of the joint may be taken as the area of the butt joint plus one half the throat area of the fillet. If the fillet throat area is more than that of the butt, the safe design area is the area of the butt plus one third the throat area of the fillet.

- Ferrules for stud welding are sintered in a continuous furnace to secure a resistance of 5 to 25 ohms in a $^{3}/_{8}$-in. ferrule.

FRANCE

Articles in the French welding magazine *Soudage et Techniques Connexes* for March-April 1960 discuss the application of welding in chemical plants and steel mills. Typical of steel mill maintenance was the repair of a support bar capable of holding 20 tons of rod. The forging contained 0.50 C and 0.71 Mn. The part was torch preheated to 660° F and was torch postheated to 930° F. A brief description is given of a program controller based on cams for the automatic tungsten-inert-gas welding of electronic tubes.

NETHERLANDS

The September 1960 issue of *Lastechniek* contains a long article on the history of radiographic testing of welds. Equipment as well as standards in Europe are discussed. A second article from the National Institute of Technical Research in Helsinki, Finland, describes static and fatigue tests on welded joints containing artificial blowholes and sharp-notched slag inclusions. Although the artificial defects were revealed by radiography, they had no appreciable effect on transverse static strength. The fatigue strength was lowered if the defects extended to the surface, but not if the defects were internal.

POLAND

In the Polish magazine *Przeglad Spawalnictwa* for July 1960 a representative of a Danzig shipyard derived mathematical formulas for the power demand coefficient in shipyard and welding installations. The coefficient decreased as the number of welders was increased.

SWITZERLAND

The August and September 1960 issues of *Journal de la Soudure* contain a description of the welded fabrication of power plant equipment by Brown-Boveri. The tendency of electrodes to produce cracked welds was evaluated by depositing a bead across a stack of plates bolted together.

An article in the September issue summarizes tests by the Czech Welding Institute on polyvinyl chloride welded with a manual hot-air torch designed by the East German Welding Institute. Highest strength was secured with an air temperature of 520 to 610° F, and with a pressure of 250 psi on the filler rod, which was $^{5}/_{32}$ in. in diameter. The rod must be held at 90 deg to the surface of the work.

USSR

Avtomaticheskaya Svarka for August 1960 describes three welding courses offered at the Rostov Institute for Agricultural Machinery: (1) Theory of Welding Processes, based on the book by G. I. Pogodin-Alexeev; (2) Soldering of Metals and (3) Power Supplies for Arc Welding (96 hr).

WEST GERMANY

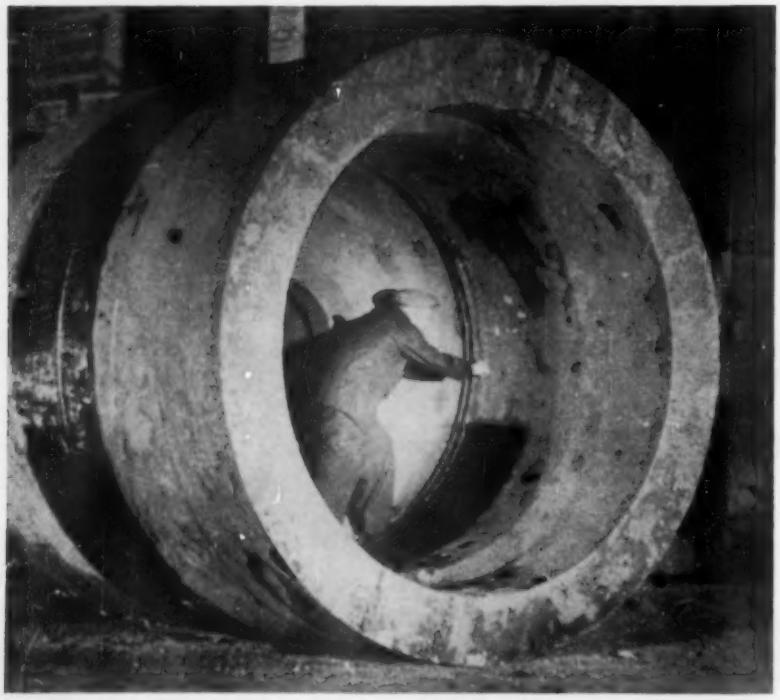
The September 1960 issue of *Schweissen und Schneiden* contains the following articles:

- An economic survey of the effect of welding on the cost of production in five different companies showed that savings followed appreciation of the flexibility of welding processes. A welded tilting railroad car for ore is described that has eight axles, weighs 60 tons and has a capacity of 180 tons.
- Several applications of welding on German railways are described.
- An economic survey is given for 1959 for the production of electric welding equipment. Production amounted to 98 million marks ($25 million) in 1959 compared with 86.5 million in 1958, an increase of 14%. Internal consumption and export increased in the same ratio. The number of units produced was: 3200 welding generators (up to 400 amp); 150 welding generators (over 400 amp); 26,600 welding transformers (up to 400 amp); 800 welding transformers (over 400 amp); 2250 welding rectifiers; and 3241 spot welders.

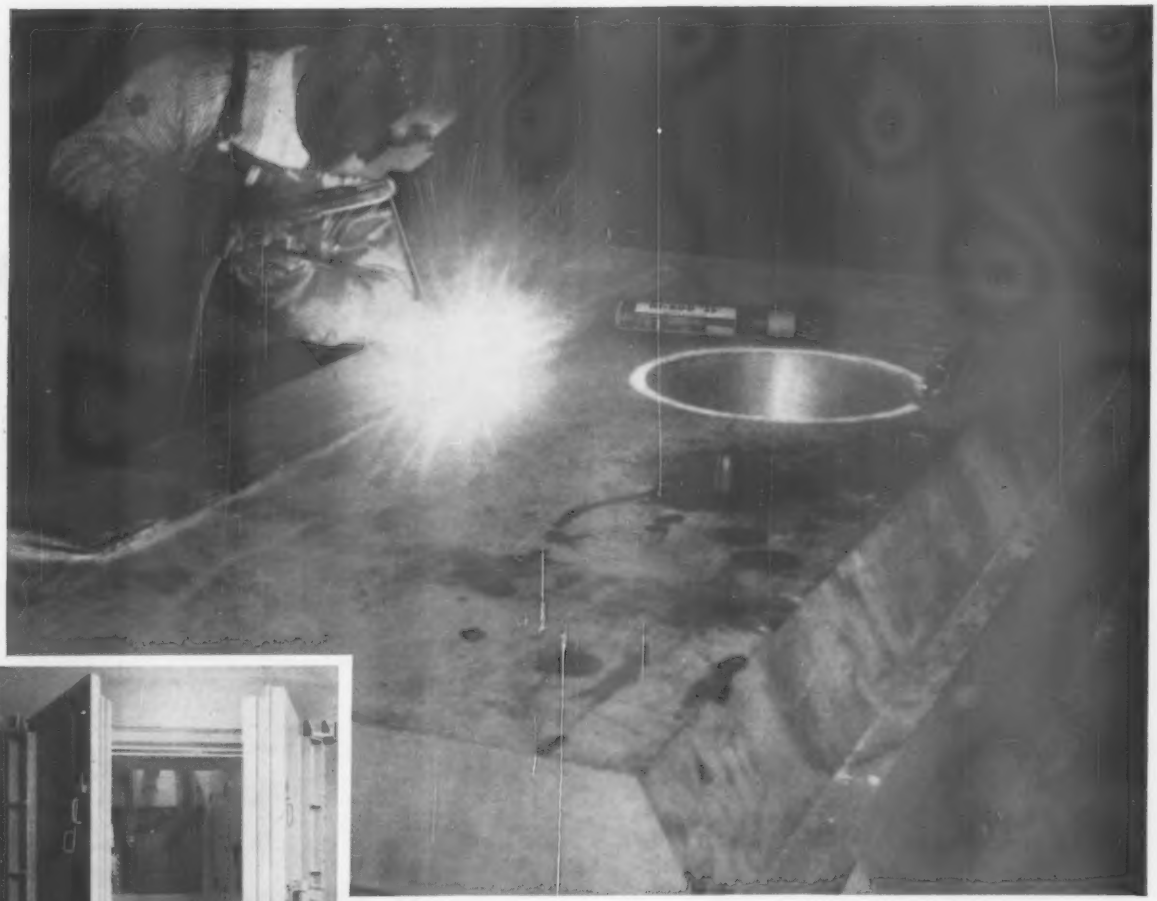
Using 1951 as a base of 100, production in 1959 was 337 for electric welding equipment, 211 for covered electrodes and 288 for the electrical industry as a whole.

- Several applications of welding to light agricultural machinery are maintained.
- The design principles are explained for fabricated welded columns for building construction.

USSR



Tubing welded by the electroslag method in the Soviet Union



Pre-heat impossible!

Yet Ni-Rod "55" produces welds in grey iron heavy sections that are strong, sound, ductile

This was the job: construct four radiation-shielding doors and frames for the National Reactor Testing Station in Idaho—each panel 8 feet high, 5 feet wide. Total weight for door and frame assembly: 86,000 pounds.

The H. K. Ferguson Co. wanted the Olympic Welding Co., Seattle, to build the entire assembly of *grey cast iron*—with no bolted connections.

These were the welding problems: heavy welds were required to join the cast iron frame sections (approximately 7 inches thick) to a special hinge structure. Any substantial pre-heat was ruled out because of the large size of the parts to be joined.

This was the solution: Ni-Rod "55"* Electrode. This electrode was chosen after experimentation with various other electrodes. Only Ni-Rod "55" produced welds that were strong, sound, and ductile. *Welds that passed magnetic particle inspection!*

Over 500 pounds of Ni-Rod "55" went into this job. All finished welds proved sound, free of defect.

For your cast iron welding jobs, you'll find Ni-Rod* and Ni-Rod "55" Electrodes can be quite helpful. For permanent repairs in cast iron parts—to salvage defective castings—to build up worn or undersized areas—and to join cast irons to other metals.

Even weldors with limited experience can get good results with these easy-to-handle electrodes. And no special work preparation is actually needed. You'll find, too, that Ni-Rod and Ni-Rod "55" will give you machinable welds, smooth bead contour, excellent "wash," and easy slag removal.

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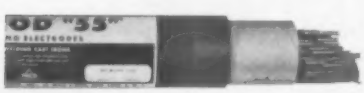

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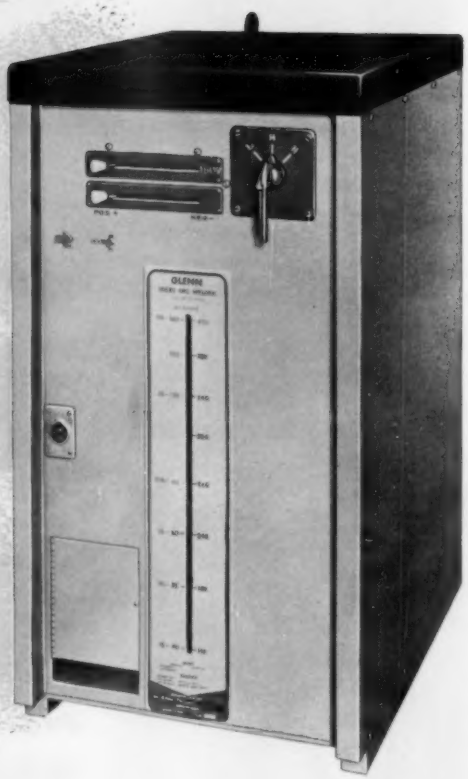

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Full-range dc output for stainless and other metals requiring dc. Built-in polarity switch.

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Built-in pulsed high frequency with automatic post-ignition cutoff control provides arc ignition without electrode contact, eliminating contamination.

Built-in automatic gas and water controls available.

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Output	Model BW400AC	BW400AC/DC
Open circuit, ac	100 or 150 v	150 v
Open circuit, dc		80 v
Current Ranges (@ 20v)		
Low	25-58 amps	
Medium	53-175 amps	
High	165-400 amps	

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Service to America

The AMERICAN WELDING SOCIETY, since its beginning, has been a *service* organization. It is true, of course, that all engineering societies are formed for the purpose of bringing together people who have a common interest; people who are designers, researchers, manufacturers, and users, and who are involved with the particular technology and processes with which each engineering society is concerned.

But AWS has been considerably more than a contact point for such people. It has been a leader in the preparation and establishment of product specifications for materials used by its members, be they manufacturers or users. It has been a highly effective sounding board and discussion point for the evaluation of new and significant welding processes. It has been a producer and disseminator of high quality technical information in a field vital to America's industry and America's survival. It has been an organization actively concerned with welding developments in all the other countries of the world, including the Iron Curtain countries. Finally, the SOCIETY has brought before the American manufacturer and the American public the *significance* of welding as an industrial process.

Yet, with all these past and continuing accomplishments, AWS is standing now on the threshold of an era during which its service to America will become more vital and of greater significance than at any previous time. This is due primarily to the advance of welding as a *technology*.

The new and important welding processes that have developed out of this technology include the electron-beam, plasma arc, friction welding, ultrasonic welding, electroslag, and explosive welding, and different carbon dioxide welding processes. Electronic tracing and cybernetic equipment is now available for flame cutting. Different compositions of shielding gas mixtures for welding many different metals have provided excellent results. Electrodes with increased deposition rates are now being used. Welding is done at heretofore "impossible" speeds. Electrode wire is now being dispensed more conveniently and efficiently on spools. New and special welding fluxes have been developed to cover a variety of welding problems. Welded structures with very high strength characteristics are being produced, and weldabilty studies have become increasingly sophisticated. Welding repair processes have found a wide range of application. Automation in welding plants has become a reality. And welding is playing a prominent part in the space program.

But the SOCIETY is not unaware of the technological shortcomings that exist, of our need to discuss and promote better welding processes to meet the continuing needs of industry for improvements and advances.

The role which AWS will play in this nation's future can be predicted by evaluation of all of the previously mentioned processes and developments. Yet this role will not be one merely of affluence, but also of *responsibility* in an international economic and productive competition.

So we go forward to meet the challenge of this new era; to meet the challenge of other nations, friend and foe, on the economic field of battle. And certainly we cannot help but be more than just a little optimistic as we look back on the past and then look forward to the future.

A. F. Chouinard

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Ignoring certain potentials of low-hydrogen electrodes by restricting their use to hard-to-weld steels raises a question . . .

Is Habit Needlessly Increasing the Cost of **Out-of-Position** Welding?

BY J. E. HINKEL

Storage tank—typical application where E-XX18 electrodes can be used advantageously to produce all-position welds in heavy plate

The case for using E-XX18 powdered iron low-hydrogen electrodes on horizontal, vertical and overhead welding applications indicates too frequently that habit needlessly increases the cost of out-of-position welding. Collected data on the application of powdered iron low-hydrogen electrode conclusively prove that E-XX18 electrodes can claim more economical and effective performance on plate thicknesses $^5/_8$ in. and greater.

Using E-XX10-11 electrodes on most out-of-position applications is generally a foregone conclusion. Gradual development over the years of a tremendous precedence for using E-XX10-11 electrodes for out-of-position welding has established a strong "habit" factor which tends to overlook the possibility of there being a better way to weld the joint. This factor exists at all levels of manufacturing, from welder through designer, and has been instrumental in retarding acceptance of the newer E-XX18 low-hydrogen electrode designs for the subject applications. Overcoming this handicap requires a logical presentation of E-XX18's advantages with respect to reducing welding cost, upgrading weld quality and improving welding conditions.

E-XX18 Electrode Attributes

Comparison to E-XX10 Electrodes

The joint design illustrated in Fig. 1 was used to develop the comparative data in Table 1 from which the stated conclusions were reached. The 60-deg, single-vee joint having a $^1/_{16}$-in. land and root opening was selected on the basis of seeking joint standardization for all three welding positions—horizontal, vertical and overhead. It is admitted a single bevel joint preparation would produce a lower cost per foot for horizontal welding. However, since relative performance of the two types of electrodes on either design is the same, it was decided that welding the same joint in all three positions would make the collected data most useful.

Calculating weld cost per foot produced parallel results in all three positions, although the percentage reduction in weld cost using E-6018 electrodes was not as great for vertical welds. In Fig. 2, weld cost is plotted against plate thickness for horizontal butt welds. As may be seen, weld cost varies directly with plate thickness, but the rate of cost increase is higher for E-6010. For this reason, plotting weld cost against plate thickness demonstrates that the E-6010 electrode produces lower cost welds on plate thicknesses to $^5/_8$ in. with the situation reversing in favor of E-6018 for heavier material. It was also determined this same condition holds true for E-6011 vs. E-6018 electrodes as well as the higher tensile cellulose and low-hydrogen electrodes. For this reason and, although 6010 is specifically compared to 6018, the remarks here apply generally to all E-XX10-11 and E-XX18 electrodes.

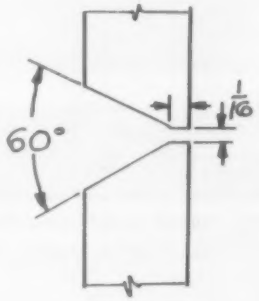


Fig. 1—Joint design used when developing comparative cost data for welding with E-6010 and E-6018 electrodes — horizontal butt weld in $^3/_4$-in. thick plate

J. E. HINKEL is Application Engineer, The Lincoln Electric Co., Cleveland, Ohio.

Paper presented at AWS National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

Deposition

Higher amperage and deposition rate put E-XX18 electrodes in a lower cost position when welding heavier plate. Figure 3 presents a size-for-size deposition rate comparison. Two conclusions can be reached by examining this chart. First, size-for-size substitution of E-XX18 for E-XX10-11 while welding with a current setting near the optimum produces a substantial increase in deposition rate.

Table 1—Calculations Showing Cost-reducing Potentials of Low-hydrogen Electrodes on Heavy Plate in Out-of-position Welding

	E-6010		E-6018	
Electrode size, in.	5/32	3/16	5/32	3/16
Current, amp (dc+)	120	170	160	240
Deposition rate, lb/hr	3.5		4.5	
Arc speed, fph	3.23		4.15	
Labor, overhead (based on $5 /hr 50% operating factor)	$3.08		$2.41	
Electrode (cost $/ft)	$0.22		$0.25	
Total cost ($/ft)	$3.30		$2.66	
Cost saving, $/ft			$0.64	
Cost reduction, %			19.4	

Note: A 60° single-vee joint preparation was used to obtain this data. Using a single bevel could have effected still greater apparent economy, but percentage reduction would remain the same.

Table 2—Effect of Narrower Bevel Joint Using E-XX18 Electrode

	Weight of weld metal deposited per foot of weld (no reinforcement considered), lb/ft
60-deg double bevel	1.089
30-deg double bevel	0.590
Weight reduction	0.499
Reduction in weld metal deposited —also welding cost, %	45.8

Table 3—Preheat and Interpass Temperatures for Manual Shielded Metal-arc Welding[a]

Thickness at point of welding	Minimum preheat and interpass Temperatures: When using E-6015 and E-6016 electrodes	When using all other class E-60 electrodes
Plates to 1 in. thick, inclusive	None required	None required
Plates over 1 in. to 2 in. thick, inclusive	None required[b]	200° F min
Plates over 2 in. to 4 in. thick, inclusive	100° F min	300° F min
Shapes and bars to 1/2 in. thick, inclusive	None required	None required
Shapes and bars over 1/2 in. thick to 1 in. thick, inclusive	None required[b]	100° F min
Shapes and bars over 1 in. thick	None required[b]	200° F min

[a] Reproduced from D2.0-56 AWS Standard Specifications for Welded Highway and Railway Bridges.
[b] No welding shall be done when the base metal temperature is below 10° F.

Second, if size-for-size substitution is not possible, E-XX10-11 usage is favored although the difference in deposition rate is small. In this situation, final electrode selection may also include weighing weld quality and operating conditions.

Use on Heavier Plate Thicknesses

It would be incorrect to give the impression that E-XX18 electrodes are capable of welding in all positions to the same degree as E-XX10-11 types. More fluid slag and increased size of the molten weld crater make quality weld production greatly dependent on plate thickness and condition of fit-up. For this reason, E-XX18 electrodes have little to offer on plate thicknesses through 1/2 in. E-XX10-11 faster freezing characteristics and lower slag volume are much better suited for these applications. On heavier plate where fluid slag and a larger molten crater are no longer a problem, high currents and large electrodes become practical. In fact, the use of 7/32-in. diam E-XX18 electrodes on horizontal butt welds is an accepted procedure. Additional advantage can result from higher deposition rates producing heavier bead thickness and reducing the number of passes needed to complete the joint.

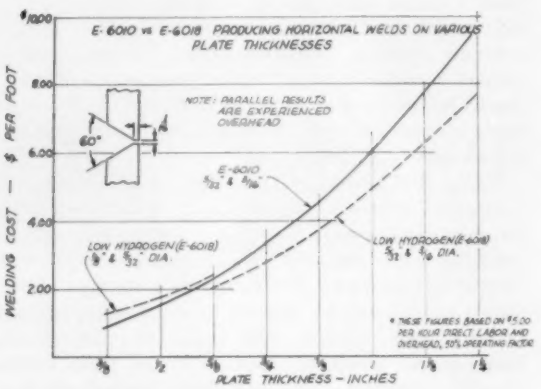

E-6010 vs E-6018 PRODUCING HORIZONTAL WELDS ON VARIOUS PLATE THICKNESSES
NOTE: PARALLEL RESULTS ARE EXPERIENCED OVERHEAD
60°
E-6010
LOW HYDROGEN (E-6018)
LOW HYDROGEN (E-6018)
WELDING COST — $ PER FOOT
PLATE THICKNESS — INCHES

Fig. 2—Weld cost comparison for E-6018 and E-6010 electrodes

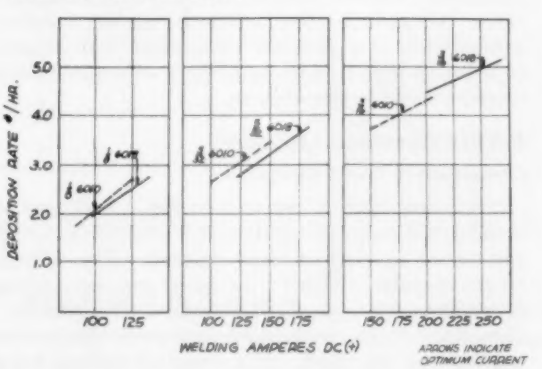


Fig. 3—Size-for-size comparison of E-XX10-11 and E-XX18 deposition rates—shows low hydrogen advantages in all cases

Reduced Joint Bevel

Figure 4, together with Table 2, illustrates another proved method for lowering weld cost. Here the designer has taken advantage of low hydrogen operating characteristics and reduced joint bevel appreciably. The resulting 45.8% reduction in weld volume lowers weld cost in the same proportion.

Preheat

Maintaining good weld quality on heavy plate frequently demands preheating. Unfortunately, this adds substantially to the welding cost. A comparison of tensile strength and ductility of welds made with identical preheat demonstrates E-XX18's unqualified advantage over E-XX10-11 electrode. In all cases, the need for preheating is either eliminated or at least the degree required is appreciably reduced. Industry-wide acceptance of this fact is found in the AASHO Bridge Code which reduces preheat requirements when low hydrogen electrodes are used (Table 3). In many instances, this advantage alone makes E-XX18 selection the economical choice.

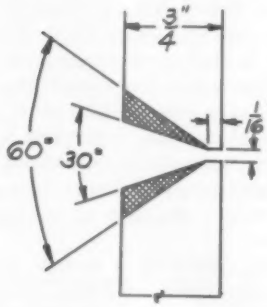


Fig. 4—Joint design with reduced bevel angle to produce further economies with E-XX18 electrode

X-ray Tests

X-ray comparison (using recommended procedures with both electrodes) shows near perfect results with E-XX18, while E-XX10-11 photographs consistently contain some very fine scattered porosity. Quality variation in this case is minor, however, since both electrodes easily meet ASME standards. Operating characteristics are primarily responsible for the observable difference. E-XX18 electrodes combine a forceful arc with high deposition, "fill" action as compared to E-XX10-11 having a forceful arc, low deposition, "fast freeze" action. On lighter plate, high deposition handicaps E-XX18. This situation reverses as the plate thickness increases with the results illustrated in Figs. 5 and 6. On material over 1/2 in. thick, the welder finds it difficult to control the E-XX10-11 tendency to undercut and develop porosity along the top edge of the bead.

Concept of Electrode Mileage

"Electrode Mileage" is another characteristic worthy of discussion. Defined as the length of weld per stick of electrode, mileage controls the number of stops, starts and electrode changes. Reduction of the number of stop-start areas in a weld deposit is desirable since these areas are susceptible to developing weld porosity, trapping slag and cracking more than any other part of the weld. Figures 7 and 8

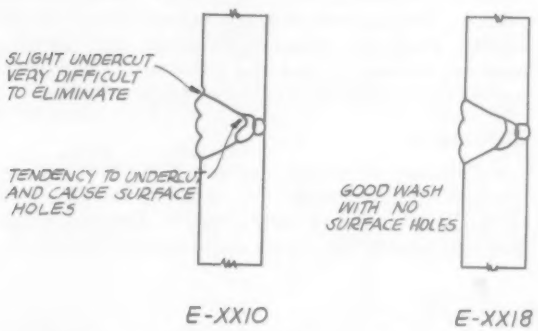

SLIGHT UNDERCUT VERY DIFFICULT TO ELIMINATE
TENDENCY TO UNDERCUT AND CAUSE SURFACE HOLES
GOOD WASH WITH NO SURFACE HOLES
E-XX10
E-XX18

Fig. 5—Effects of electrode arc characteristics

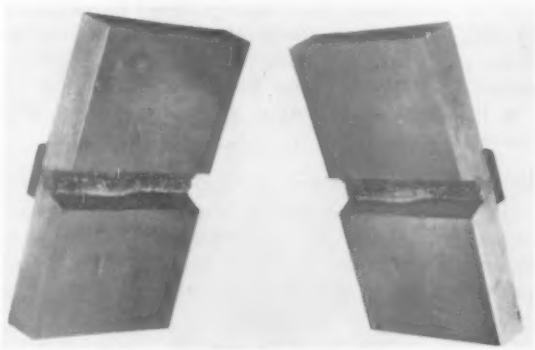
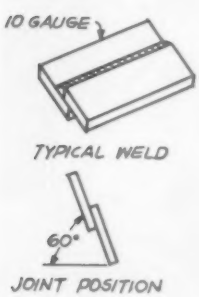


Fig. 6—Comparison of welds made with E-XX10 electrode (left) and E-XX18 electrode (right)



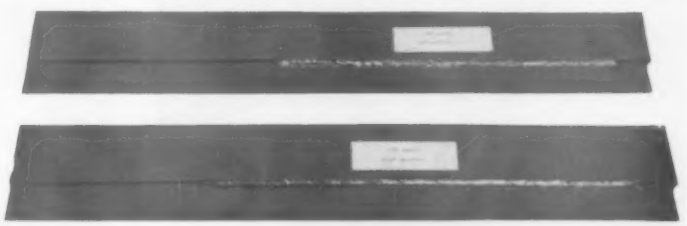


Fig. 7—Conditions for 1/8- and 5/32-in. diam electrodes and sample welds obtained in mileage comparison analysis. Top weld made with E-XX10 electrode; longer bottom weld made with E-XX18 electrode

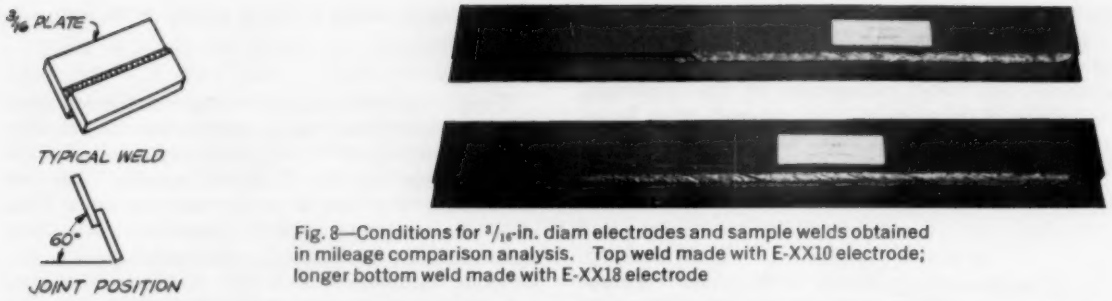


Fig. 8—Conditions for $^{3}/_{16}$-in. diam electrodes and sample welds obtained in mileage comparison analysis. Top weld made with E-XX10 electrode; longer bottom weld made with E-XX18 electrode

together with Table 4 compare electrode mileage for $^{1}/_{8}$-, $^{5}/_{32}$- and $^{3}/_{16}$-in. diam electrodes and, in the case of E-XX18, show a marked advantage which increases with electrode size.

Realizing the production advantages of E-XX18 electrodes depends on the welder learning proper welding techniques. While not difficult to master, they differ from the E-XX10-11 out-of-position techniques that most welders have been brought up on. Here the effect of "habit factor" is most apparent. Usually a welder training period that includes unlearning as well as teaching is necessary before production economies from E-XX18 conversion can be achieved. The operator must be taught to replace electrode whipping with a short arc stringer bead technique and learn to control higher current and deposition rate while traveling at a relatively slow speed.

After conversion, most welders object to returning to E-XX10-11 usage. Quieter arc action, fewer stops and starts has made controlling weld quality easier and welding less fatiguing. Referring to Fig. 9, reduction in spatter also contributes to this change in attitude.

Unusual Conditions

Joint conditions occasionally complicate the out-of-position use of E-XX18 electrode on heavy plate. Common sense introduction of modified procedures can usually solve these problems without condemnation and complete elimination of low-hydrogen electrode. Figure 10 together with Table 5 illustrates such a solution. Combining usability characteristics of E-XX10-11 and E-XX18 has produced a solution for handling a difficult root pass situation while retaining maximum production economy. Figure 11 demonstrates another situation that if not properly handled can defeat use of E-XX18 electrode. This condition, usually posing no major problem for E-XX10-11, is one area where low-hydrogen suffers by comparison. Since weaving, whipping or breaking the arc has a detrimental affect on low-hydrogen weld quality, correcting a condition of poor fit usually demands use of backing strips, spacer blocks, buttering plate edges or some other method that will reduce the gap to where effective handling is possible.

Figure 12 illustrates the results of a change in technique that improves appearance. Vertical butt welds are normally made "vertical up" (from bottom to top). Using these same procedures with E-XX18 usually produces excessive build-up and inferior bead appearance. Changing to vertical down welding, for the cover pass only, corrects the problem.

Conclusion

Fabricators no longer question the superiority of low-hydrogen electrode for welding hard-to-weld steel (Fig. 13 and lead photograph). Unfortunately, they also tend to restrict its use to applications of this

Fig. 9—Quiet arc action of E-XX18 electrode (right) reduces spatter and improves operating conditions for welder; arc action of E-XX10 electrode shown to left

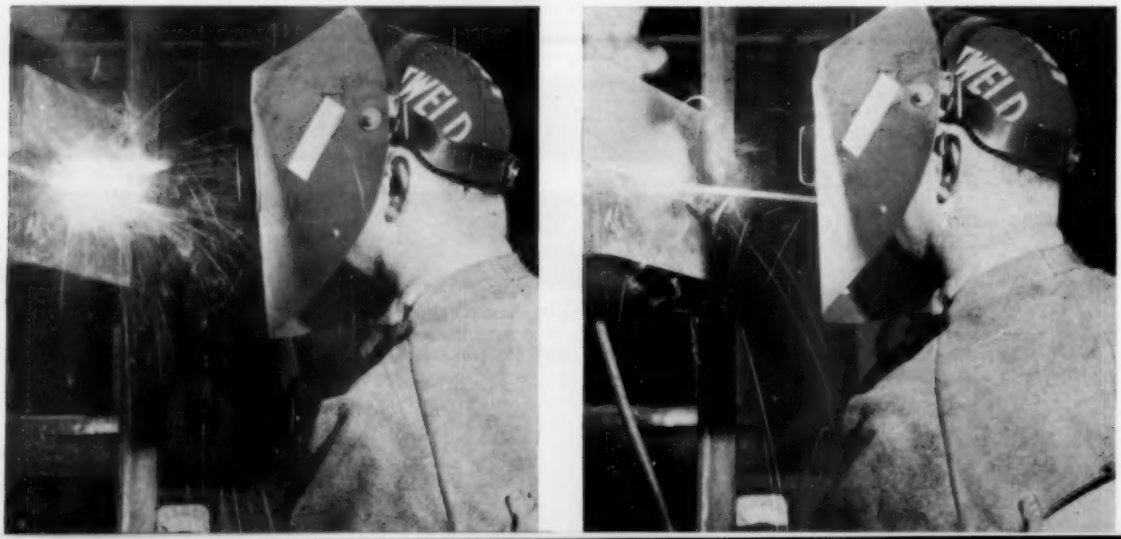


Table 4—Mileage Comparison

	E 6010	E-6018	E-6010	E-6018	E-6010	E-6018
Electrode diameter, in.	1/8	1/8	5/32	5/32	3/16	3/16
Optimum current (DC +), amp	100	115	130	165	160	225
Average arc speed, ipm	10	10.5	11.5	14.25	10.0	12.0
Mileage, in. weld/electrode	10.0	12.0	13.5	17.75	12.0	16.0
Mileage advantage, %	...	20	...	31	...	33

Table 5—Welding Procedures When Backing Strip Is Not Practical

Pass No.	Electrode Type	Electrode Size in.	Welding techniques	Welding amperage
1	E-XX10	1/8	Vertical down	90–110
2	E-XX18	5/32	Vertical up	70–90
3, 4	E-XX18	1/8	Vertical up	115–125

type. Due to this fact, the ability of low-hydrogen electrode to reduce cost and improve the quality of welds made out of position on heavy plate has been largely overlooked.

Admittedly, conversion from the present techniques that are based on E-XX10-11 usage will require a training program of unlearning and reteaching to overcome deeply entrenched operator habits. However, this initial cost is small when compared to the improvements in quality and cost that can be realized.

Fig. 10—Technique when use of backing strip is not practical. E-XX10 used for first pass; E-XX18 used for remaining passes

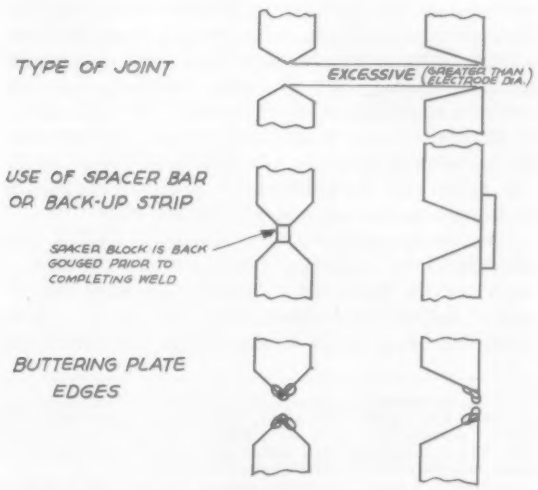

TYPE OF JOINT
EXCESSIVE (GREATER THAN ELECTRODE DIA.)
USE OF SPACER BAR OR BACK-UP STRIP
SPACER BLOCK IS BACK GOUGED PRIOR TO COMPLETING WELD
BUTTERING PLATE EDGES

Fig. 11—Welding technique with E-XX18 electrodes in joints having excessive openings

Fig. 12—Improved appearance of weld made with E-XX18 electrode when using vertical-down instead of vertical-up cover pass

Fig. 13—Typical structure fabricated from fairly heavy plate using low-hydrogen electrode

Application of wide-gap brazing material in slurry form with an air-operated gun

"Wide-Gap" Brazing for High-Temperature Service

involves the use of recently-developed brazing materials and furnace brazing techniques to braze joint gaps up to 0.060 in.

BY P. R. MOBLEY AND G. S. HOPPIN, III

SYNOPSIS. An inherent problem that has long limited the application of furnace brazing to the fabrication of large sheet metal structures is the requirement that all joints to be brazed must have essentially capillary clearances of 0.002 to 0.006 in. The manufacturing costs inherent in obtaining such close tolerances on large fabricated structures have been sufficiently high to preclude the use of standard brazing processes. Experimental work in the past few years has led to the development and successful application of novel brazing materials and furnace brazing techniques to reliably and reproducibly braze parts with joint gaps up to 0.060 in. In addition to being capable of brazing these "wide gaps," the family of new brazing materials developed has exhibited useful strength and good oxidation resistance up to temperatures of 1800° F. A number of different jet engine parts have been fabricated by these new materials and techniques. The largest part successfully brazed with them was over 6 ft in diam and contained over 700 individual brazed joints. Parts joined with wide-gap brazing materials have successfully operated for several hundreds of hours in the 1500–1800° F range.

Success with the wide-gap furnace brazing process was found to be contingent on very close control of the following process variables: (1) the use of sluggish brazing materials containing both solid and liquid phases at the brazing temperature, (2) the ratio of constituents in these brazing materials, (3) the brazing temperature, (4) heating and cooling rates, (5) furnace atmospheres and (6) joint designs. The limitations found on these variables are reported. Some mechanical properties of joints brazed with wide-gap brazing materials are also reported

Introduction

Definitions of high-temperature and wide-gap brazing are in order to best explain the process developed. As defined herein, both high-temperature and wide-gap brazing are processes producing joints suitable for elevated temperature service (to 1200–1800° F). High-temperature brazing can be defined as "a group of welding processes whereby coalescence is produced by heating to a suitable temperature above 1800° F and by using a nonferrous filler metal having a melting point below that of the base metals. The filler metal is distributed between the closely-fitted surfaces of the joint by *capillary attraction*, and during brazing, atomic diffusion of certain elements occurs between the brazing alloy and the parent metals joined." For wide-gap brazing, the last sentence should be changed to read "The filler metal is distributed and *preplaced manually* between the joint faying surfaces in a quantity sufficient to fill the joint, and during brazing, atomic diffusion of certain elements occurs in the brazing alloy."*

The development of new brazing materials and techniques for wide-gap brazing stemmed from a need for an improved fabrication process for jet engine turbine nozzle assemblies—see Fig. 1. These parts are often made of superalloys that are quite

* These definitions differ from the AWS definition of brazing in that the AWS definition refers to "heating to a suitable temperature above 800° F" and does not mention atomic diffusion as a mechanism of bonding. The definitions proposed above are appropriate for specialized cases, while the AWS definition is more general in nature.

P. R. MOBLEY and G. S. HOPPIN, III, are with the Flight Propulsion Laboratory Dept., General Electric Co., Evendale, Ohio.

Paper presented at the AWS National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

difficult to weld, and weld cracking has often been a problem with them. The parts are sufficiently large (3 to 4 ft in diam) that normal manufacturing procedures and tolerances result in fit-ups between detail parts that can range from line contact to 0.060 in spacings. The application of conventional brazing with the AWS BNiCr type alloys was therefore impossible, as these brazing materials require 0.001–0.005-in. joint clearances.

It was known at the onset of the development work that any material which would successfully braze joints with large gaps must possess exceptionally sluggish flow characteristics. It had previously been discovered during the course of experimental work on brazed stainless steel honeycomb structures that the addition of 20% by weight of elemental nickel powder to J8100 brazing powder (70Ni – 20Cr – 10Si) created a brazing material (J8102) which had flow properties quite inferior to J8100, although J8102 did braze thin stainless steel honeycomb well with minimum erosion. Therefore, it was believed that the poor flow properties imparted by the nickel additions might be utilized to develop an unconventional brazing material for bridging wide joint gaps. Consequently, initial efforts to develop a wide-gap brazing material involved adding various percentages of elemental nickel powder to powder brazing alloys. Subsequent development work has shown that blending of diverse alloy powders is the key to successfully producing wide-gap brazing materials.

The mechanism by which these materials bridge large gaps was postulated as follows: At brazing temperature, one alloy powder melts, while the other does not. The result is a viscous slurry, with poor flow characteristics, formed wherever the powders have been preplaced. This slurry then metallurgically bonds itself to the two abutting members of the assembly, producing a "wide-gap brazed" joint.

Initial Development of the Process

There are many aircraft gas turbine parts on which normal manufacturing procedures make tight clearances impossible. As mentioned previously, one

Fig. 1—Jet engine turbine nozzle assembly

such part is the turbine nozzle diaphragm. The normal method of manufacturing this part is to weld individual sheet metal nozzle partitions (vanes) into the inner and outer bands of this assembly. While this operation is not particularly difficult when the materials of construction are easily weldable, it is costly and difficult when highly alloyed base metals susceptible to weld cracking are used. For this reason, it became most desirable to develop brazing techniques to manufacture these parts. The clearances between the partitions and their band slots normally range from line contact to 0.060 in., making a conventional brazing operation impossible. As stated earlier, unconventional brazing materials possessing exceptionally sluggish flow characteristics were needed to bridge these large joint gaps. Therefore, experimental work was initiated in 1956 which resulted in the first truly wide-gap brazing material for elevated temperature use. This material—a mechanical mixture of 60% J8100 and 40% elemental nickel powders—was designated "J8101." (Table 1 lists all brazing alloy compositions referred to in this paper.)

Developing the J8101 material required determining the effectiveness of various brazing techniques and mixtures of brazing materials on test samples simulating the joint gaps found in the nozzle dia-

Table 1—Nominal Compositions by Weight Percentage for Reported Brazing Materials

Brazing material	Composition, wt-%							Solidus temp., °F	Liquidus temp., °F	Brazing temp., °F	Remarks
	Ni	Cr	Si	Cu	Mn	B	C				
J8100	Bal.	20.0	10.0	...	...	...	...	2030	2075	2125–2175	Capillary brazing alloy
J8590	28.0	...	2.0	Bal.	10.0	...	...	1850	2000	2050–2100	Capillary brazing alloy
AMS4775	Bal.	16.5	4.0	...	...	3.75	0.95	1850	1950	2100–2150	Capillary brazing alloy
NSB	Bal.	...	2.0	...	...	0.8	...	1980	>2300	>2300	Used as filler alloy for wide-gap brazing
J8101	60% J8100 + 40% nickel powder									2240	Wide-gap brazing material
J8105	70% J8100 + 30% NSB powder									2125–2175	Wide-gap brazing material
J8591	80% J8590 + 20% iron powder									2050–2100	Wide-gap brazing material

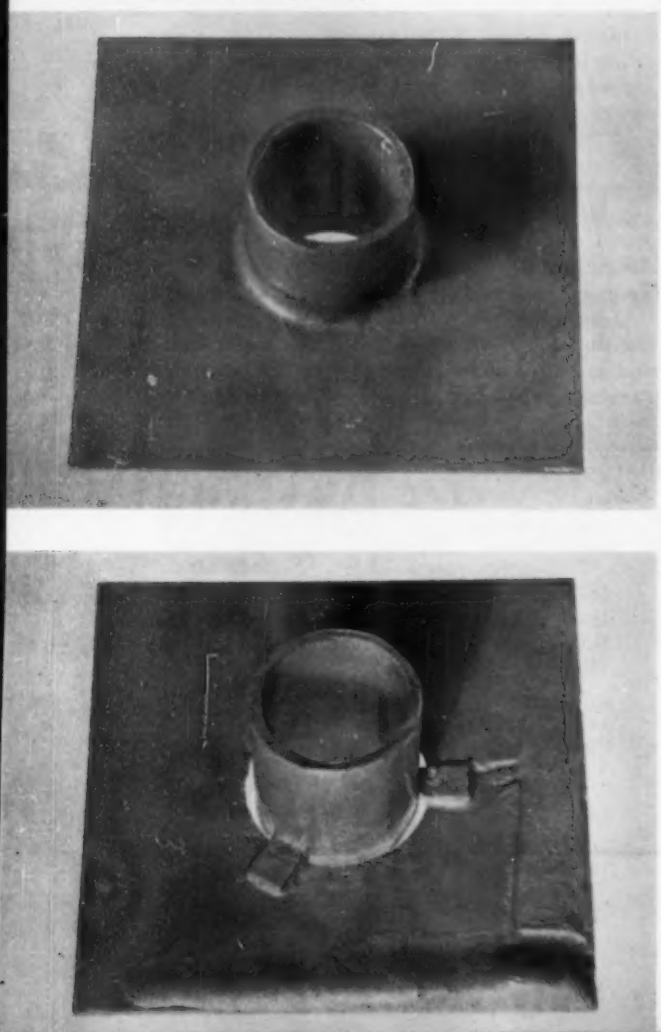
NOTE: All powders used are —100 mesh materials.

phragm. One such sample consisted of a 1-in. OD Type 321 stainless steel tube which was fitted through drilled holes of various diameters in 3-in. square 0.063-in. thick Type 321 stainless sheets. Three small locating lugs were resistance welded to the sheets to ensure uniformity of joint gaps around the periphery of the tube. A total of six assemblies and four mechanical mixtures of brazing materials were tested before the first useful wide-gap brazing material was identified. This material (J8101) required a furnace brazing temperature of 2240° F in an atmosphere of purified hydrogen.

A number of further experiments were made on the tube-to-sheet assemblies to prove that the satisfactory early results could be reproduced and to refine the technique. These experiments indicated that the following elements of technique were required for consistently good wide-gap brazing:

1. The gap to be filled must be tightly packed with the brazing powder mixture. Excess material (about 100%) must be placed around the joint to compensate for solidification shrinkage.

Fig. 2—Tube and plate samples of Type 321 stainless brazed with J8101 wide-gap brazing material (top) and J8100 capillary brazing alloy (bottom). Original joint clearance on both samples was 0.055 in. Plates were positioned vertically in the furnace during brazing



2. Close control must be exercised over the heating and cooling rates of the brazing cycles.

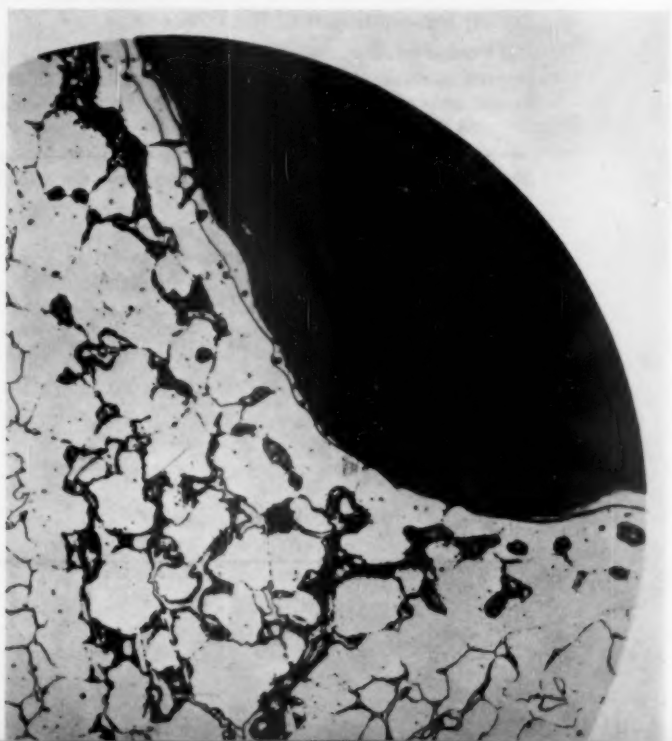
3. Brazing temperatures must be much more closely controlled than with conventional furnace brazing. Temperature measurement is critical.

The experiments also showed that results in wide-gap brazing are not influenced by the position of the part in the furnace as is the case when attempting to fill wide-gap joints with capillary brazing alloys. Figure 2 shows tube and plate samples with a joint gap of 0.055 in. brazed with J8101 and the capillary alloy J8100. These samples were both brazed with the plates in a vertical position. Note how the capillary alloy has run out and not filled the gap.

A fairly clear understanding of the wide-gap brazing mechanism also resulted from this early work. Heterogeneous brazing materials are essential to wide-gap brazing. These materials should consist of fine powders (about 200 mesh) of a relatively low melting alloy mixed in intimate dispersion with similar fine powders of a second metallic material which does not melt during the brazing process. When this mixture is tightly packed into the gap to be brazed and heated to a suitable temperature, a process analogous to infiltration of powder metallurgy compacts occurs during "brazing."

During heating to the brazing temperature, the two metals in the brazing mixture sinter to each other and to the pieces being joined. Then at the brazing temperature, the lower melting material melts and flows into the interstices between the sintered particles of the higher melting material and the pieces being joined. The driving force for this flow is capillarity, which operates strongly in small passages,

Fig. 3—Microstructure of joint brazed in L605 with J8101 wide-gap brazing material at 2240° F. X 100. (Reduced 30% on reproduction)



such as the gaps between sintered particles (or close brazing gaps), but is completely ineffective across gaps in the 0.050–0.060-in. range. The flow normally experienced with standard brazing alloys is not characteristic of wide-gap brazing materials.

Figure 3 is a photomicrograph of a joint brazed in L605 cobalt base alloy with J8101. Note the dispersion of the low melting alloy in the grain boundary structure surrounding the nickel particles.

Process Variables

There are numerous variables affecting the success of the wide-gap furnace brazing process. Some of these are:

1. Joint design and joint clearances.
2. Cleanliness of the joint faying surfaces.
3. Joint or part fixturing.
4. Application of the brazing material.
5. Brazing temperature measurement.
6. Brazing thermal cycles.

For the sake of clarity, each of the above variables must be discussed separately.

Joint Design and Joint Clearances

The best joint designs for wide-gap brazing are those where "tee" or fillet joints are produced. Clearances for these joints, which should be readily accessible for brazing alloy preplacement, may range from capillary clearances to 0.060 in. Conversely, the worst joint designs for wide-gap brazing are long lap joints, in which it is difficult to preplace brazing alloy, and where "feeding" of the joint by brazing alloy flow is required.

If it is necessary to wide-gap braze lap joints, their length should not exceed $^1/_4$ in. and they should have clearances in the range 0.025–0.060 in., where the joints can be packed with brazing alloy powder prior to brazing. A most undesirable situation is to attempt wide-gap brazing of capillary clearance lap joints. When this is done, the low melting material in the wide gap brazing powder mixture is sucked into the capillary gap, leaving a porous skeleton of the sintered higher melting material on the exterior of the joint.

As a general rule, wide-gap brazing materials should be applied to joints designed for these materials, and capillary brazing alloys used on capillary joints. Wide-gap brazing is not a cure-all for sloppy fits caused by poor manufacturing practices on parts designed for capillary brazing. Figure 4 shows some good and bad joint designs for wide-gap brazing.

Joint Cleanliness

The cleanliness of joints is necessarily a function of both joint preparation and the cleaning action achieved by reducing atmospheres during actual furnace brazing. Preparation of joint surfaces prior to brazing alloy application should follow established procedures for various base materials. Maintaining base metal cleanliness during brazing requires different furnace atmospheres for various types of materials. Nickel-base superalloys containing relatively large amounts of titanium and aluminum require a vacuum or flux for high-temperature brazing. Joint cleanliness and furnace atmospheres required for wide-gap brazing are identical with similar requirements for good high-temperature furnace brazing.

Fixturing

The fixturing of assemblies for wide-gap brazing is usually less difficult than for welding. Furnace brazing uniformly heats the entire part and its fixturing, resulting in uniform thermal expansion and metal movement. Therefore, many of the fixturing problems encountered from localized heating during welding are nonexistent. Fixturing materials used should have thermal expansion properties similar to those of the part materials.

In every case fixturing for furnace brazing must take into account movement of the entire part during thermal cycling. Insufficient fixturing may result in joint gap increases causing a loss or starvation of brazing alloy in the joint. Over-fixturing can inhibit uniform heating and cleaning of its part through excess mass and part shielding. The simplest and lightest fixture that is efficient for any given part is the best for that job.

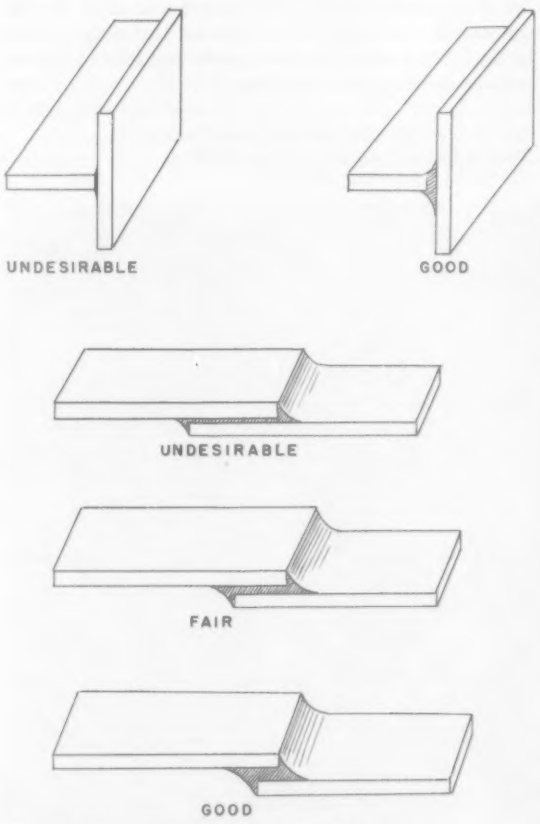


Fig. 4—Joint designs for wide-gap brazing

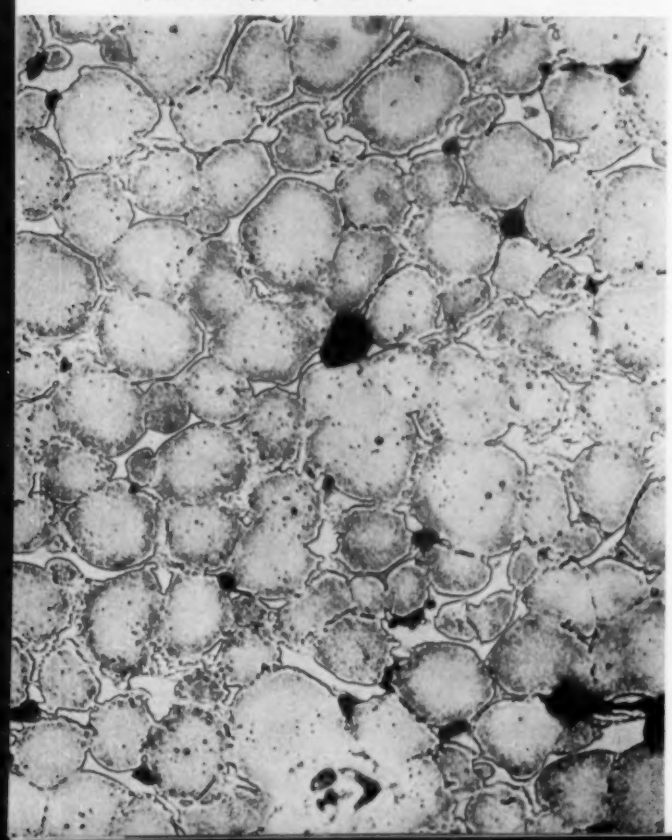
Brazing Alloy Application

The application of brazing alloy for wide-gap brazing differs from conventional capillary brazing in that the brazing material must be tightly packed into the joint including preplacement of the fillets. The sluggishness that is characteristic of wide-gap brazing materials make it imperative that the alloy be preplaced in the joints. Due to lack of joint capillarity and the sluggishness of the wide-gap brazing materials, wide-gap joints cannot be filled or bridged if the brazing alloy is preplaced only at the joint openings.

Application of the wide-gap brazing material can be successfully achieved manually or with such equipment as air-operated guns—see lead photograph. In both cases, the alloy is applied as a slurry in an acrylic cement binder. In many cases the application technique will be dictated by part design.

An important item of wide-gap brazing alloy application technique is the use of "stop-off" materials to restrict any flow of liquid-phase material out of the joint area. Stop-offs are stable oxides of such reactive metals as aluminum, titanium or magnesium. They are commercially available as water slurries and can easily be painted around the joint edges with a small brush. The white material around the joints of Fig. 3 is stop-off. Stop-offs, which are not wetted by brazing alloys, function as dams to retain all the liquid brazing alloy in the preplaced locations. This assures the proper ratio of liquid and solid phases in wide-gap brazing materials at brazing temperatures.

Fig. 5—Microstructure of joint brazed with J8105 wide-gap brazing material. X 100. (Reduced 30% on reproduction)



Temperature Measurement

Temperature measurement for brazing is a continual point of controversy. In the writers' opinion, the only meaningful temperature for furnace brazing is that temperature read from thermocouples imbedded in or welded to the part being brazed. Significantly true temperature measurement on large parts can be achieved by strategically positioning thermocouples throughout the part and attaching the thermocouple heads directly to the part by resistance welding. Temperatures read by this method are pertinent to the brazing operation, whereas temperatures read from furnace controlling instruments are often irrelevant. Use of the above method will, in many cases, result in a lower apparent brazing temperature for any given brazing alloy and increase the percentage of consistency for brazing operations.

Brazing temperatures for wide-gap brazing materials are of necessity those which are normal for the lower melting alloys in the powder mixture. Brazing temperatures higher than these decrease the wide-gapping efficiency of those materials. In general, excessive brazing temperatures will increase hydrogen pickup (causing joint porosity), and result in increased erosion of parent metals by nickel-base brazing alloys. All of these effects can only result in materially reducing joint properties. Measuring true part temperature should promote lower brazing temperatures and optimum properties from the brazing alloy and brazed joints.

Brazing Thermal Cycles

Brazing thermal cycles are significantly important to most high-temperature brazing operations because of the wide melting ranges which are both common to high-temperature brazing materials and vitally important to wide-gap brazing materials. In particular, slow heating rates will cause dissolving of the base metals by phases liquating from the brazing alloy, resulting in an increased brazing temperature for the brazing alloy due to compositional changes occurring as it alloys with the base metal. If slow heating rates are employed, the brazing temperature must be increased or incompletely brazed parts result. With wide-gap brazing materials, the lower melting alloy tends to alloy rapidly with the high melting alloy during heating because of the high surface/volume ratio of the powders. This reaction occurs far more rapidly than alloying of "straight" high-temperature brazing alloys with base metals.

With wide-gap brazing materials, slow heating rates can result in a porous joint of unmelted material due to the increase in brazing temperature caused by interalloying at the constituent powders during heating. Optimum heating rates appear to be on the order of 20° F/min or faster through the melting range of the lower melting constituent. Good brazing practice is to achieve such rates from about 100° F below the solidus temperature of the lower melting alloy up to the brazing temperature.

Generally, cooling rates can be fairly rapid. How-

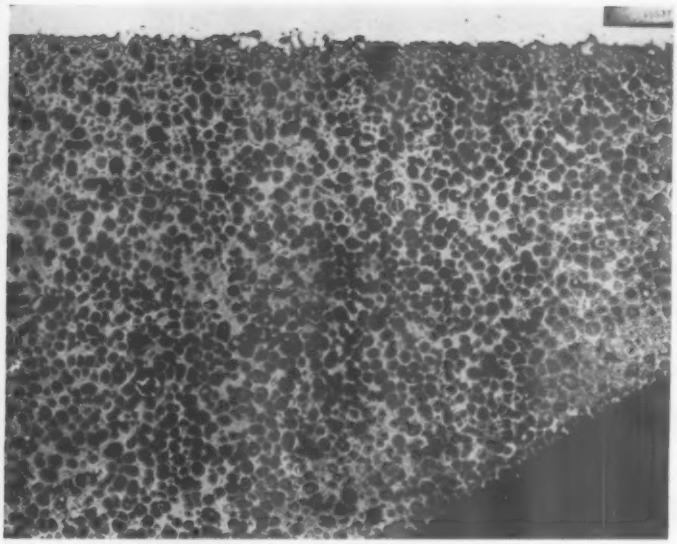


Fig. 6—Microstructure of joint brazed with J8591 wide-gap brazing material. X 100 (Reduced 30% on reproduction)

ever, two limitations do exist. They are:

1. Joint cracking resulting from severe thermal stresses.
2. Porosity caused by entrapment of gases in the joint due to insufficient time for gas evolution from the brazing material.

In summary, heating rates should be rapid through the melting range of the low melting constituent of the brazing material. In addition, cooling rates should be compatible with the thermal contraction of the part and should be sufficiently slow through the solidification range of the brazing alloy to permit evolution of dissolved hydrogen and thus prevent joint porosity.

Wide-gap Brazing Materials

The initial wide-gap brazing material developed (J8101) produced satisfactory joints but was unsuited for many applications due to its high brazing temperature (2240° F). This temperature was above the grain growth temperature of most austenitic materials and near the incipient melting temperature of some. Consequently, a search for a variant of this brazing material having a lower brazing temperature was instituted. The search revealed that the nickel powder could be replaced with an alloy ("NSB") of nickel, boron and silicon having the composition: Si, 2.0; B, 0.8; Ni, balance. The silicon and boron in this alloy were sufficiently low to allow only slight melting of the alloy at brazing temperatures of 2100–2200° F. Studies showed melting of this alloy to begin at 1980° F (the nickel-boron eutectic temperature)[1] and yet be incomplete at 2350° F. At 2150° F, about 10% of this alloy was molten. It was felt that the use of "NSB" powder instead of pure nickel as a "filler" would be an improvement, as the liquid formed on the surface of "NSB" powder particles at brazing temperatures would facilitate complete wetting of the particles by the J8100 brazing alloy.

It was found that mixtures of J8100 and the "NSB" alloy would produce wide-gap joints in the 2125–2150° F brazing range with NSB in the range 20–40 wt-%. One wide-gap brazing material standardized upon from this alloy mixture system was J8105, containing 30 wt-% "NSB," balance J8100. Figure 5 is a photomicrograph showing the two-phase structure formed by brazing J8105 at 2150° F. Some porosity is present, but the duplex structure is quite evident.

Experiments have been made in applying the wide-gap brazing principle to a number of other alloy systems. It has been found to work with copper powder additions to silver brazing alloy powders, and with iron powder additions to a copper base brazing alloy powder. One material from the latter system has been standardized upon as J8591 (80% of a copper-base alloy—J8590—containing 28% Ni – 10% Mn and 2% Si, mixed with 20% elemental iron powder). Figure 6 shows the microstructure of J8591 brazed at 2050° F.

As mentioned above, it appears that the wide-gap brazing principle is applicable to a wide variety of brazing alloy systems. Other investigators have found it to work on nickel-base brazing alloys,[2] and the principle has been used in the past on copper brazing pastes to decrease the extreme fluidity of pure copper.[3] It is the writers' belief that extension of the principle to more alloy systems and adoption of these materials by industry should greatly widen the use of furnace brazing as a manufacturing technique.

Table 1 lists the compositions of the wide-gap brazing materials described above and compares them with their capillary alloy counterparts. The composition of AMS4775, the pioneer high-temperature brazing alloy, is also listed for comparison.

Table 2—Lap Joint Shear Strength Data[a] for Wide-gap Brazing Materials

(Base metal—0.063 in. L605 sheet; joint gap—0.045 in.; heat treatment—none after brazing)

Brazing material	Test temp., ° F	Joint overlap range, in.	Indicated shear strength, psi[b]
J8105	Room temp.	0.140–0.160	21,600
J8105	1200	0.140–0.175	19,900
J8105	1500	0.113–0.170	19,700
J8105	1800	0.158–0.170	8,600
J8591	Room temp.	0.175	27,000
J8591	1200	0.155–0.160	14,500
J8591	1500	0.160–0.185	7,200

[a] All values reported are average of four tests save room temperature results on J8591. This result is from one test—three other specimens failed in parent metal.

[b] Indicated shear strength was obtained by dividing load at failure by the original shear area of the lap joint tested.

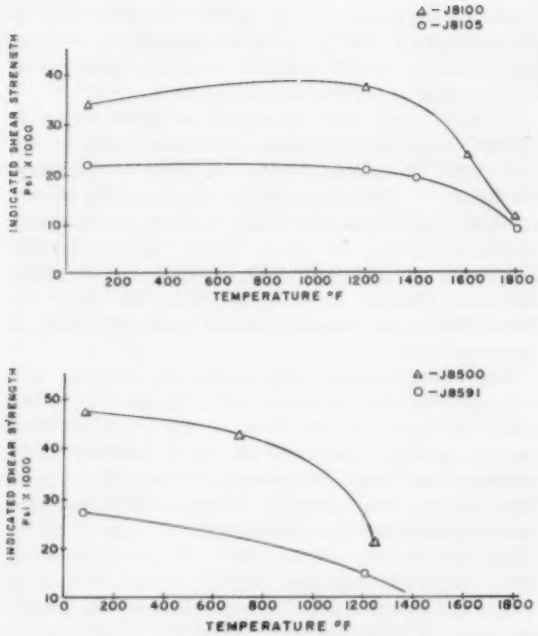


Fig. 7—Average indicated shear strength curves for two capillary alloys—J8100 and J8500—and their sister wide-gap brazing materials

Mechanical Properties of Wide-gap Brazed Joints

Shear strengths versus temperature for joints brazed across 0.060-in. gaps with wide gap materials J8105 and J8591 are presented in Table 2. For comparison, shear strengths of J8100 and J8500 brazed joints are presented in Table 3. These results are presented graphically in Fig. 7.

These values were determined on simple lap joints brazed in 0.063-in. thick sheet metal. While it is appreciated that the values presented are not true shear strengths and cannot therefore be used for design purposes, they are comparative strength levels and do show that high strengths can be obtained from wide-gap brazed joints.

Table 3—Lap Joint Shear Strength Data for Capillary Brazing Alloys

(Base metal—0.063 in. L-605 sheet; joint gap—0.003–0.005 in.; heat treatment—none after brazing)

Brazing material	Test temp., ° F	Joint overlap range, in.	Indicated shear strength, psi[a]	Notes
J8100	Room temp.	0.140–0.150	34,200	Average of four tests.
J8100	1200	0.147–0.151	37,000	Average of four tests.
J8100	1600	0.127–0.159	23,500	Average of four tests.
J8100	1800	0.127–0.150	11,300	Average of four tests.
J8500	Room temp.	0.135–0.175	47,500	Two other specimens failed in Par. Met.
J8500	700	0.130–0.170	42,400	Average of four tests.
J8500	1250	0.135–0.175	20,100	Average of four tests.

[a] Indicated shear strength was obtained by dividing load at failure by the original shear area of the lap joint tested.

The question of what constitutes a valid test of brazed joint shear strengths is currently being investigated by an AWS Subcommittee, and the values presented will have to be compared in the future with the Subcommittee's findings. Figure 8 shows the design of the shear strength specimen used for these tests.

Applications

The wide-gap brazing process has been applied to a number of experimental and production jet engine parts in addition to the original turbine nozzle assembly application. Figure 9 is an inlet vane assembly wide-gap brazed of Type 321 stainless. Figure 10 shows a vacuum brazed strut assembly made of A286. This wide-gap brazed assembly was the result of a design study to replace a difficult-to-produce casting. Figure 11 shows a jet engine exit

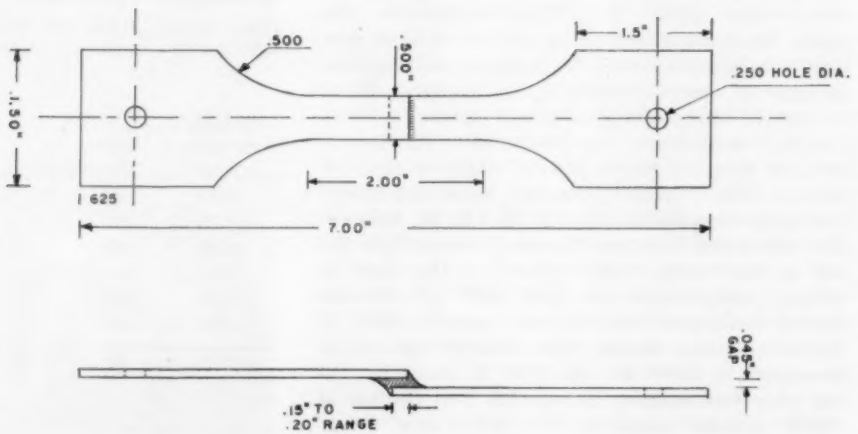


Fig. 8—Shear strength test specimen used for tests of wide-gap and capillary brazing materials

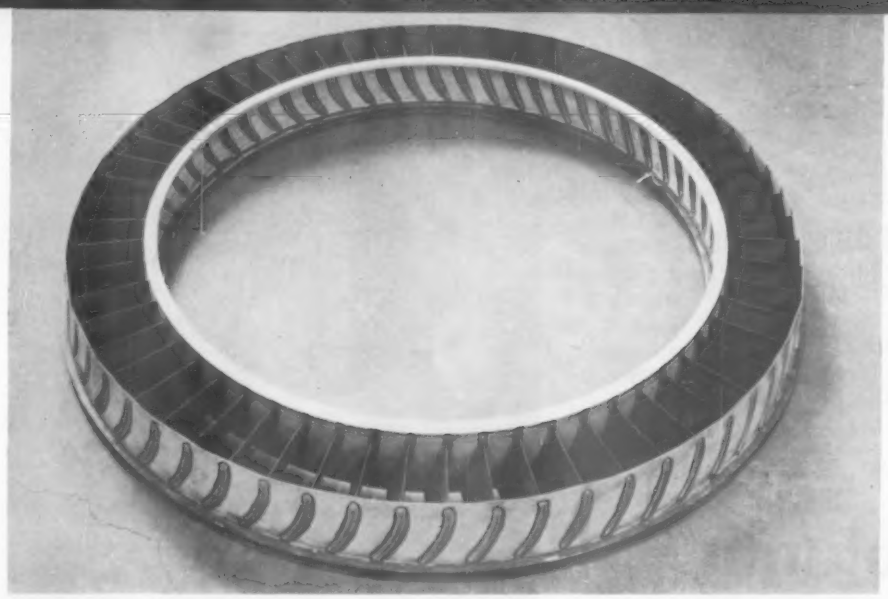


Fig. 9—Wide-gap brazed inlet vane assembly of Type 321 stainless steel

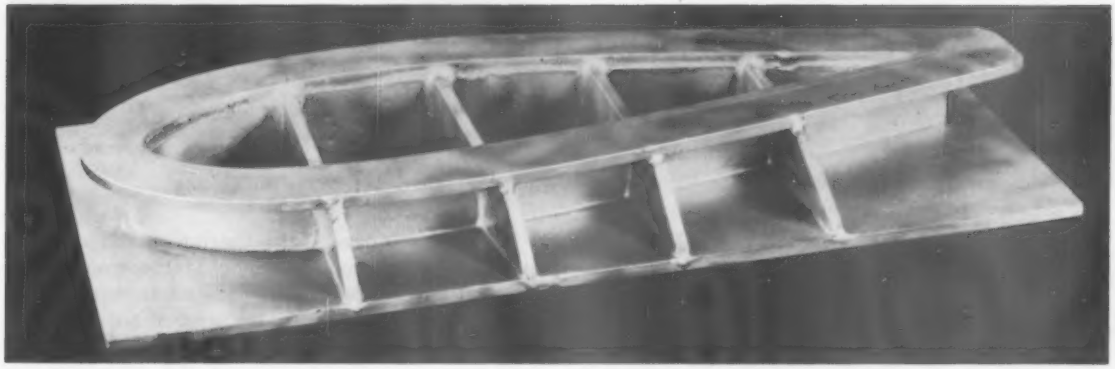


Fig. 10—Strut assembly wide-gap brazed in vacuum. Part is made of A286 high-temperature alloy

frame assembly made of Inconel X. This part contained over 700 brazed joints and exceeds 6 ft in diam. While many of the military jet engine applications of the process are understandably classified at this time, it is significant that parts are being produced, some of them successfully operating at temperatures up to 1800° F.

Acknowledgments

The development of the wide-gap brazing process at General Electric has been a cooperative effort to which many individuals have made major contributions. Foremost among those who have contributed to the development are Messrs. R. H. Schwegman, R. G. Kellner, K. S. Songer, E. G. Huschke, Jr., M. D. Kiessling and W. R. Young. The authors express thanks to these individuals, and to the many others who have translated the process from idea into reality.

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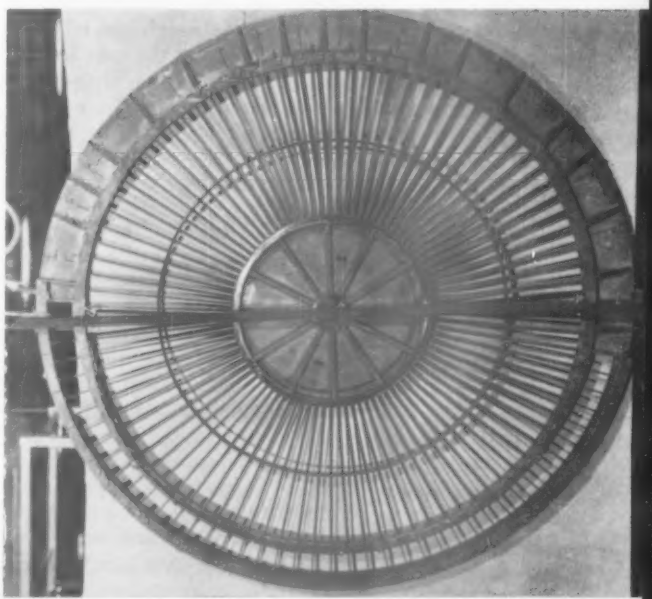
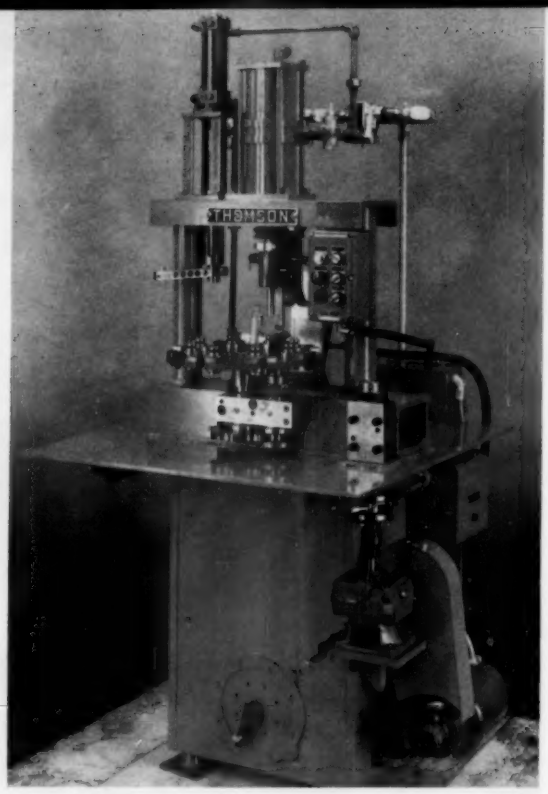


Fig. 11—Jet engine exit frame assembly of Inconel "X" wide-gap brazed

Lack of mechanical deflection and equal flow of electric current throughout the weld area in the welding of transistors are two keys to

Where **Two-Column** Welding Machines Stand Today

BY F. P. JACOB



Two-column unit is coordinated with automatic dial table for transistor welding

A projection welding machine designed with a two-column frame in principle has a distinct advantage over a C-type frame. Parts are not subjected to deflection; consequently, weld pressure can be applied with more uniformity. Obviously, this means better welding control.

That C-frame units continue to be used in spite of the fact that some deflection is inherent is because other considerations—the configuration of the work, for example—can outweigh the effect of deflection. This is, however, not the case in projection welding—particularly with ring projections. Parallelism between the platens and absence of deflection are imperatives if quality is to be a goal. As indicated in Fig. 1, the two-post design more readily satisfies these conditions.

Requirements of Transistor Welding

Transistor welding more than any other one thing points up this fact. Until semiconductors came on the scene, C-frames were preferred, even when welding small parts. In the first place, their design is such that they are economical to build and the best machine in the world is not worth much if its costs counteract its functional merits. Secondly, the number of times a resistance weld had to be made to prescribed and exacting specification was, until recently, limited indeed. Then, when the situation did arise, a two-column unit could be tailored to meet the occasion. But it was considered—and priced—as a "special"; stocked standard C-frame machines continued to dominate in most areas.

F. P. JACOB is Vice President and Sales Manager, Thomson Electric Welder Co., Lynn, Mass.

Transistors arrived, and the fat was in the fire. By themselves small, their weldable components demanded the ultimate in pressure control and in weld quality. Hermetical seals defied any less than perfection. Companies engaged in the business soon recognized that a slightly higher investment in welding equipment could feasibly lead to higher product yields and, in the long run, to some real savings. This led to extensive work on the two-post machine. Starting with two column machines previously made on a special basis, modifications upgraded design basics and refinements upgraded modifications. New machines to meet the transistor challenge were introduced, and their success soon was assured.

New Two-post Machines

Providing a balanced welding force around the circumference of an annular ring, the new units feature two tubular columns between which are mounted an overhead air cylinder and the top electrode (lead photograph). Thrust is applied downward, parallel to the posts, and converged at and around the annular projection ring on the work. Conditions that can lead to mechanical deflection are avoided completely. Additional benefits are as follows:

1. The equal distribution of forces around the annular ring encourages equal flow of electric current throughout the weld area. The pedestal design that normally is utilized permits the arrangement of two, diametrically opposed, secondary circuit transformers for ring diameters over $1/2$ in.; this optimum assures distribution of welding current around the entire ring (Figs. 2 and 3).

2. A rapid, follow-up action of the welding head is an imperative design adjunct that adds to the quality of a machine. This is accomplished in two-column equipment by a diaphragm-type air cylinder which has (*a*) relatively no hysteresis and (*b*) an extremely light head-and-piston assembly mounted on ball bushings. Even under light application of force by the air cylinder, the low inertia welding head accelerates rapidly as the projection ring melts.

3. Good access to the work is obtained between the columns, and a minimum of electrode maintenance leads to higher welding rates than is practical with C-frame units.

Positioning of tooling is relatively simple, and there are no appreciable forces acting on the platens to cause misalignment, even on long production runs. This, too, emphasizes faster production runs. Parts feeding can be performed quickly; the machine operator has better visibility of the work (Fig. 4). The open design of the head as well as the access of the controls and transformers measurably reduce maintenance.

4. Machine versatility is demonstrated by the variety of ring diameters and metals used in transistor production. Stringent quality control programs testify to the ability of holding close tolerances on high-production but precision work.

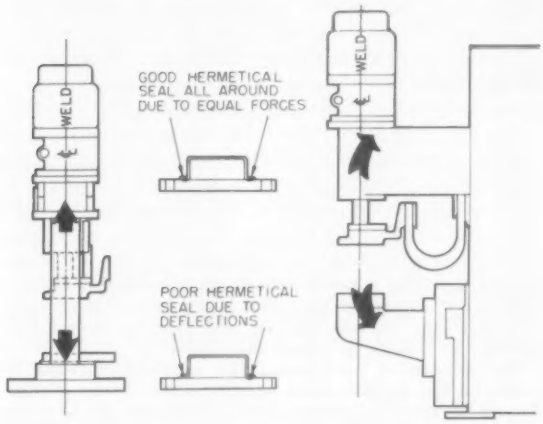


Fig. 1—Lines of force in C-frame machines (right) and two-column machines (left). Welding applications that mandate a perfect seal have accelerated the development of two-column units

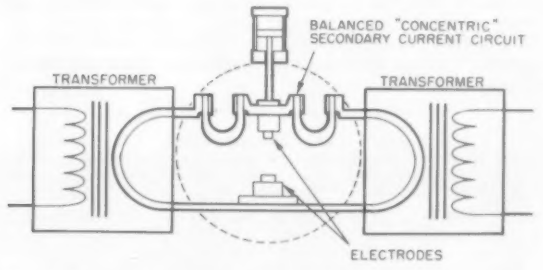


Fig. 2—Several benefits in electrical conductance are realized in a two-column design. Secondary circuits can be arranged to use either (a) one transformer and increase the short circuit secondary amperage, or (b) both transformers to balance weld current throughout the ring projection

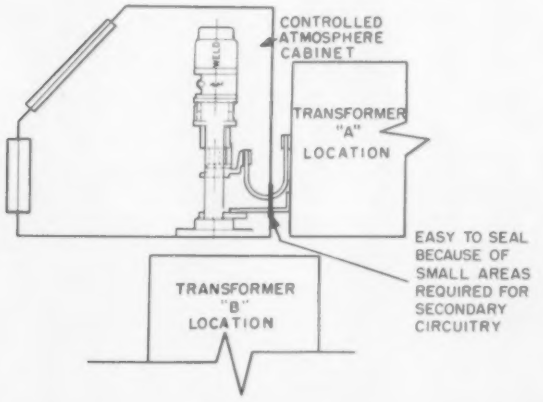

CONTROLLED ATMOSPHERE CABINET
WELD
TRANSFORMER "A" LOCATION
EASY TO SEAL BECAUSE OF SMALL AREAS REQUIRED FOR SECONDARY CIRCUITRY
TRANSFORMER "B" LOCATION

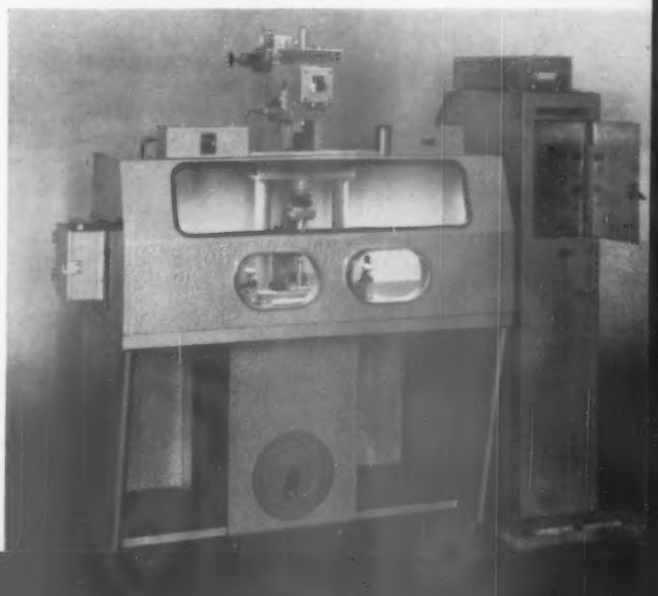
Fig. 3—Two-post machines are conducive to controlled atmosphere installation. Access between the columns and the operators in attaining high welding rates

Future Potentials

The successful debut of two-column machines opens the gates to other industrial avenues. But no one is going to escort them in. They will have to find their own way, and certainly there will be detours. The cost of the design in comparison to C-frame units of equal size must be reduced, and buyers must be convinced of the value of the quality it introduces. In the past this was not easy. The trend, fortunately, is shifting, thanks principally to the demanding consumer.

In some markets, however, it is unlikely that C-frames will even be subordinated. The two-post machine is tailored to small products, and there is little evidence that it can be recruited for relatively large components. However, circumstances do change as was proved by the advent of transistors, and the future may hold some surprising developments.

Fig. 4—Welding machine enclosed in a dry box is fed manually and circuited by palm switches



Fabrication of One-Inch Thick, Ten-Inch Diameter **Welded Inconel** Pipe

involves thirteen-step hot-forming process as well as both gas tungsten-arc and gas metal-arc welding

BY W. L. FLEISCHMANN AND R. F. GURNEA

Tungsten-arc welding of 1-in. thick Inconel pipe

ABSTRACT. This paper gives the mechanical and metallurgical data taken on specimens of the Inconel plate and pipe after the various heating and forming operations involved in making of a fabricated pipe.

The fabricated pipe meets the mechanical requirements of the Inconel plate Specification Sb-168 of the ASME Boiler and Pressure Vessel Code and the quality requirements of welded pipe stipulated in ASTM A358-56T specification for electric-fusion-welded austenitic chromium-nickel alloy steel pipe for high temperature service.

The particular plate discussed in this paper was sensitive to the welding process used. Welding with coated electrodes and the tungsten-arc process produced sound welds while the heat-affected zone of the weld made by the gas-shielded-arc consumable-electrode process showed fissures. These fissures are associated with segregate regions in the base metal.

W. L. FLEISCHMANN is with the Knolls Atomic Power Laboratory, Schenectady, N. Y., operated by the General Electric Co. for the U. S. Atomic Energy Commission; R. F. GURNEA is associated with the Midwest Piping Co., Inc., St. Louis, Mo.

ASME sponsored paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif, Apr. 25–29, 1960.

Fig. 1—"U" ing operation

Introduction

The fabrication process described here is the first application of the Midwest Piping Co. hot forming process to the fabrication of Inconel piping. As the mechanical properties of the finished pipe must meet a specification requirement of 80,000 psi minimum tensile and 30,000 psi minimum yield strength of Inconel plate and also the soundness requirements of the ASTM specification for electric-fusion-welded austenitic chromium-nickel alloy steel pipe for high temperatures service (ASTM Designation—A358-56T), it was necessary to establish in detail the effect of successive heating and cooling cycles on the properties of the pipe formed from plate. It was also necessary to determine the quality of the longitudinal weld. To obtain these data, a surveillance pipe was fabricated from Inconel plate so that specimens could be removed at the important manufacturing steps.

This paper describes (*a*) the hot-forming process for manufacturing the Inconel pipe, (*b*) the test program by which the properties of the Inconel were established, (*c*) a report on the quality of the pipe, and (*d*) results of the metallographic investigation of the longitudinal pipe weld.

Manufacturing Process

Basically the hot-forming process for manufacturing Inconel pipe consists of the following thirteen operations:

1. Cut blanking
2. Heat blanking
3. "U" blanking—Fig. 1
4. "U" heating
5. Partial closing—Fig. 2
6. Reheating
7. Closing—Fig. 3
8. Machine grooving
9. Welding—Figs. 4, 5, and lead of photograph
10. Heating the welded pipe
11. Sizing—Fig. 6
12. Annealing
13. Machining

Available information of the effect of successive heating and cooling on the mechanical properties of Inconel is rather sketchy. However, INCO Bulletin T-11 ("Forging INCO Nickel Alloys") considers 1850 to 2300° F as the allowable heating range with the easiest bending from 1900 to 2250° F. Section VIII of the ASME Boiler and Pressure Vessel

Fig. 2—Partial closing operation

Fig. 3—Closing operation

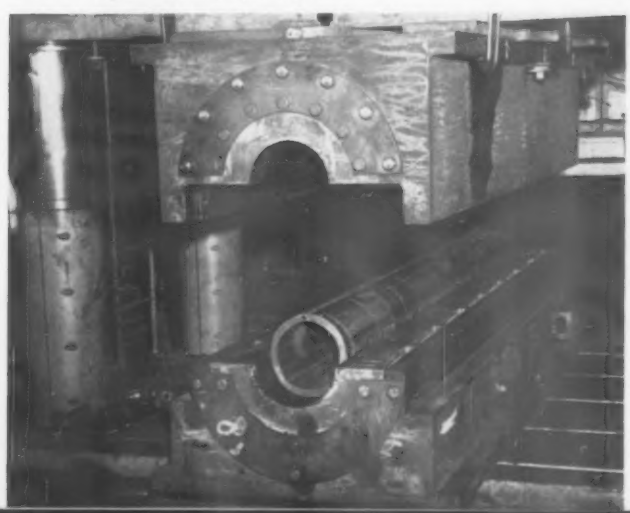


Fig. 4—Making weld preparation

Fig. 5—Gas-shielded-arc consumable electrode welding

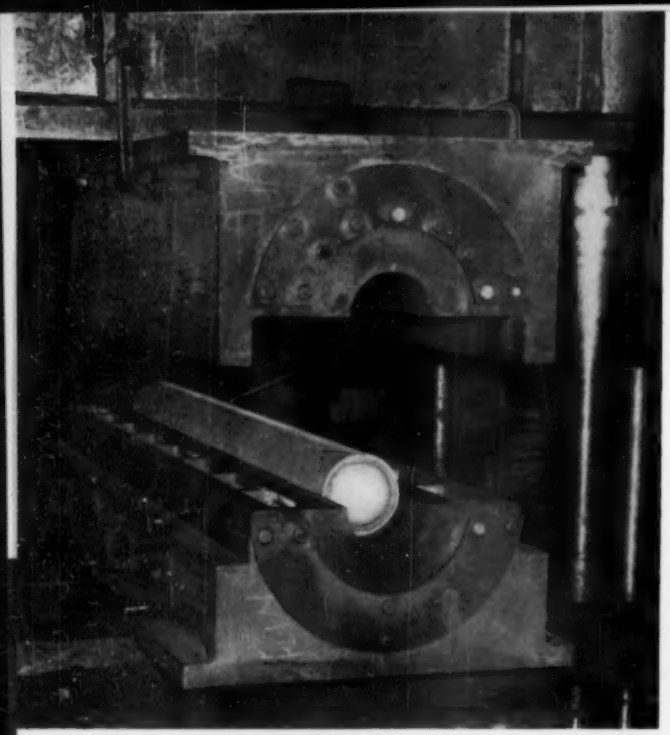


Fig. 6—Sizing operation

Table 1—Chemical Composition of Test Plate Heat No. 9781-1

	KAPL[a] spec. for plate, %	Mill analysis of plate, %	KAPL[a] analysis, %
Carbon	0.08, max	0.02	0.03
Nickel	72.0, min	76.28	75.32 ± 0.5
Chromium	14.0 to 17.0	16.03	15.76
Iron	6.0 to 10.0	7.10	7.21
Manganese	1.0, max	0.18	0.21
Silicon	0.50, max	0.19	0.20
Sulphur	0.015, max	0.007	...
Cobalt	0.10, max	0.18[b]	0.08
Copper	0.50, max	0.17	0.08
Aluminium	0.40, max (0.20 aim)	...	0.07
Titanium	0.50, max (0.25 aim)	...	0.18
Magnesium	...	...	0.003 (spectrographic)
Boron	...	...	0.003 (spectrographic), 0.008 (wet chemical)
Vanadium	...	...	0.06 (spectrographic)

[a] KAPL = Knolls Atomic Power Laboratory.
[b] St. Louis Test Lab. Analysis

Table 2—Mechanical Properties of Test Plate; Specimen 514

Bar No.	Yield,[a] psi	Tensile, psi	Elongation, %
F[b]	42,000	93,400	59.0
G	49,122	95,789	41.5
G	37,290	94,144	46.5
G	37,102	93,587	47.0
G	37,153	93,297	46.5

[a] Yield determined by 0.2% offset method.
[b] Results obtained from mill report.
Heat cycle: as received; hot rolled annealed.

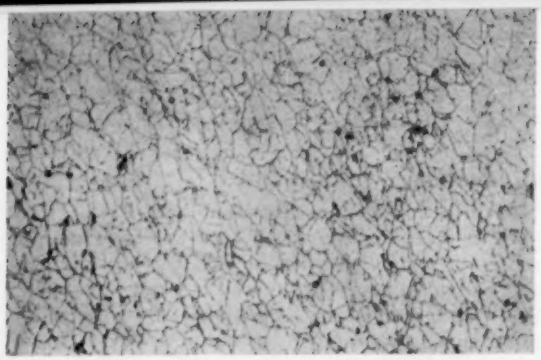


Fig. 7—Photomicrograph of specimen removed from as-received plate. Specimen No. 514; etchant 10% NaCN. X 100

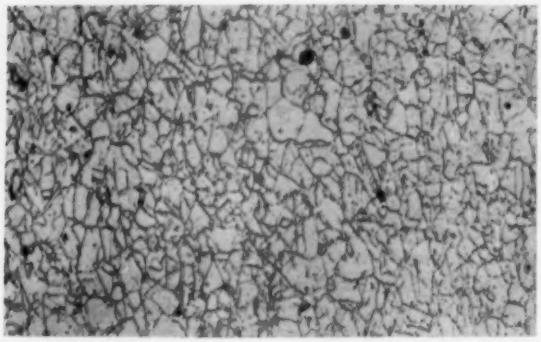


Fig. 8—Photomicrograph of specimen after heating to 1750° F for 10 min. Specimen No. 505; etchant 10% NaCN. X 100

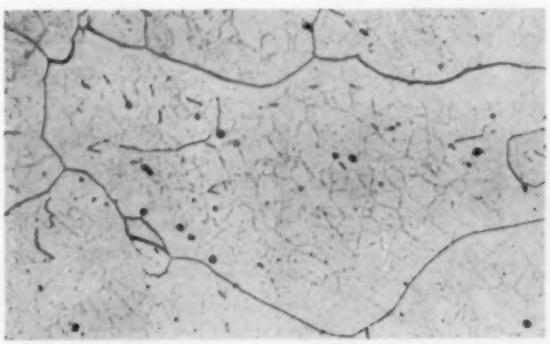


Fig. 9—Photomicrograph of specimen after heating to a maximum of 1865° F, two cycles. Specimen No. 512; etchant 10% NaCN. X 100

Code (Table NF4 of Appendix NF) is not specific as to the maximum temperature to which Inconel may be heated without affecting the mechanical properties of the finished product; it permits heating of Inconel up to 2300° F.

From research done at the Oak Ridge National Laboratory,[1] it was known that grain growth of Inconel is very rapid at the high heat-treating temperatures allowed by the Code. Since grain size is related to yield strength, it is necessary to limit the time at temperature and maximum temperature so that the grain growth is held within acceptable limits.

Test Program

For this test program in which tensile test specimens were to be taken after each combination of

heating and forming operation, a plate was ordered to ASTM Designation B-168. Table 1 gives the chemical composition and Table 2 the mechanical properties of the plate. The strength values of the plate are perhaps on the low side because of the low carbon content.

Effect of Heating Upon the Mechanical Properties of Inconel

In the previously outlined manufacturing process, the Inconel material is heated to hot-working temperatures four times during pipe fabrication. Thus, the effect the repeated heating on the yield strength of the Inconel has to be known. In order to obtain information on this effect, a series of Inconel test bars were given various heat cycles as outlined in Table 3 which also presents the mechanical properties obtained as a result of the different heat treatments. Photomicrographs indicating grain size produced by those heat treatments are shown in Figs. 7, 8, and 9.

Effect of Heating and Forming Upon Mechanical Properties of Inconel

The results of these tests were utilized to set the heating cycles for forming the plate. It was recognized that the plate had to be heated to a higher temperature than the forming operation requires because the plate would cool in the die. The working at the lower temperature was assumed to be beneficial for re-establishing high mechanical properties.

In order to obtain this data, a 10.750-in. OD pipe was manufactured by hot-forming plate following the time temperature cycle outlined in Table 4, with actual results tabulated in Table 5.

After each forming operation material sufficient to make standard tensile test bars were cut. The location of these samples are shown in Figs. 10–13.

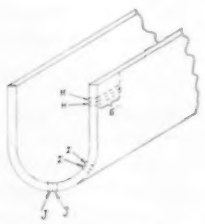


Fig. 10—"U"-ed section

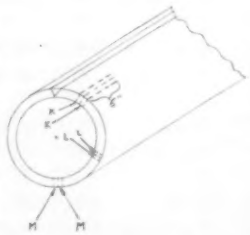


Fig. 11—Closed section

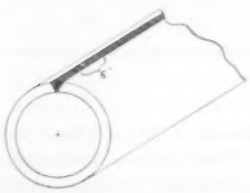


Fig. 12—As-welded section

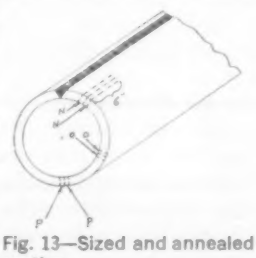


Fig. 13—Sized and annealed section

Table 3—Effect of Heating Upon the Mechanical Properties of Inconel

Bar No.	Specimen	Yield,[a] psi	Tensile, psi	Elongation, %	Heat cycle
A	504	38,022	94,162	47.0	1750° F, 10 min, air cooled
A	505	36,541	93,182	47.0	
B	506	35,488	93,283	46.5	1865° F, 10 min, air cooled
B	507	30,926	87,166	53.0	
C	508	37,367	91,318	49.0	1765° F, 10 min; 1765° F, 10 min; 1865° F, 10 min; 1865° F, 10 min. Air cooled between each heat cycle
C	509	34,348	91,092	50.0	
D	510	35,388	91,303	49.5	1865° F, 15 min, air cooled
D	511	38,558	92,380	48.5	
E	512	26,649	85,463	50.0	1765° F, 15 min; 1765° F, 15 min; 1865° F, 15 min; 1865° F, 15 min. Air cooled between each heat cycle
E	513	30,654	84,698	52.5	

[a] Yield determined by 0.2% offset method.

Table 4—Time and Temperature Cycle

Operation	Temperature range,[a] ° F	Max. time at temp., min
"U" ing	1750–1765	10
Partial closing	1750–1765	10
Closing	1850–1865	10
Sizing	1750–1765	10
Anneal	1750–1765	10

[a] Controlled closely by an observer using an optical pyrometer.

Table 5—Forging and Annealing Operations

U-ing operation
- Temperature at time of removal from furnace, ° F.....1760
- Temperature at start of press, ° F.....1670
- Temperature at finish of press, ° F.....1600

Partial closing operation
- Temperature at time of removal from furnace, ° F.....1760
- Temperature at start of press, ° F.....1680
- Temperature at finish of press, ° F.....1640

Closing operation
- Temperature at time of removal from furnace, ° F.....1850
- Temperature at start of press, ° F.....1790
- Temperature at finish of press, ° F.....1725

Sizing operation
- Temperature at time of removal from furnace, ° F.....1750
- Temperature at start of press, ° F.....1650
- Temperature at finish of press, ° F.....1575

Annealing operation
- Temperature, ° F.....1750
- Time at temperature, min..... 10
- Cooling.....Air cool

Table 6—Mechanical Test Results for Samples

Bar No.	Specimen	Yield,[a] psi	Tensile, psi	Elongation, %	Operation	Furnace	Heat cycle start press, ° F	Finish press, ° F
H	516	31,863	89,203	51.0	U'ing	1760/10 minutes	1670	1600
H	517	33,967	92,560	48.5	U'ing	1760/10 minutes	1670	1600
I	518	43,359	93,859	47.0	U'ing	1760/10 minutes	1670	1600
I	519	45,017	94,992	46.5	U'ing	1760/10 minutes	1670	1600
J	520	44,530	94,082	46.0	U'ing	1760/10 minutes	1670	1600
J	521	42,835	93,787	46.0	U'ing	1760/10 minutes	1670	1600
K	522	35,896	87,443	52.5	Partial close	1760/10 minutes	1680	1640
					Close	1850/10 minutes	1790	1760
K	523	35,395	91,533	47.0	Partial close	1760/10 minutes	1680	1640
					Close	1850/10 minutes	1790	1760
L	524	42,211	92,086	47.0	Partial close	1760/10 minutes	1680	1640
					Close	1850/10 minutes	1790	1760
L	525	40,726	92,118	47.5	Partial close	1760/10 minutes	1680	1640
					Close	1850/10 minutes	1790	1760
M	526	39,781	92,018	47.0	Partial close	1760/10 minutes	1680	1640
					Close	1850/10 minutes	1790	1760
M	527	41,762	92,835	46.5	Partial close	1760/10 minutes	1680	1640
					Close	1850/10 minutes	1790	1760

[a] Yield determined by 0.2% offset method.

Table 7—Mechanical Test Results for Final Plate

Bar No.	Specimen	Yield,[a] psi	Tensile, psi	Elongation, %	Fabricated pipe operation	Furnace	Heat cycle start press, ° F	Finish press, ° F
At location of original leg of U	KAPL 528	33,600	88,400	50.8	Sizing	1750/10 minutes	1650	1575
		35,796	90,039	49.5	Annealing	1750/10 minutes AC[b]		
At location of U-curve section	KAPL 529	37,500	88,600	50.0	Sizing	1750/10 minutes	1650	1575
		36,146	90,389	49.0	Annealing	1750/10 minutes AC[b]		
O	530	35,107	89,557	49.5	Sizing	1750/10 minutes	1650	1575
					Annealing	1750/10 minutes AC[b]		
O	531	35,778	88,737	49.5	Sizing	1750/10 minutes	1650	1575
					Annealing	1750/10 minutes AC[b]		
P	532	33,900	90,500	49.2	Sizing	1750/10 minutes	1650	1575
		37,119	90,639	49.0	Annealing	1750/10 minutes AC[b]		
P	533	33,000	89,800	48.5	Sizing	1750/10 minutes	1650	1575
		39,990	92,187	47.0	Annealing	1750/10 minutes AC[b]		
N		38,000	82,600	48.5	...	.....	...	Properties of finished pipe longitudinal specimens 600° F
N		32,300	82,300	49.3	...	.....	...	
P		27,500	84,000	50.0	...	.....	...	
P		29,500	84,400	50.0	...	.....	...	
		33,000	85,200	46.9	...	.....	...	

[a] Yield determined by 0.2% offset method.
[b] AC = air-cooled.

The results of the mechanical test are given in Table 6.

It is interesting to note that specimen H, which is taken from the leg of the U, has a lower mechanical strength than specimens I and J taken from the hot-worked section. These lower mechanical properties persist even after further forming operation. Thus, specimen K taken from the former leg

Table 8—Nominal Chemical Composition[a] and Mechanical Properties of INCO "62" Weld Deposit

Specimen	Yield,[b] psi	Tensile, psi	Elongation, %
All weld	61,158	93,884	43.0
All weld	60,603	93,404	42.0

[a] Nominal chemical composition (%) as follows: 0.1 OC; 1.0 Mn; 0.75 Si; 0.015 S; 14.0–17.0 Cr; 70.0 Ni; 6.00–10.0 Fe; (4xSi) Cb; 1.00 others.
[b] Yield determined by 0.2% offset method.

of the U has lower properties than specimens from section M and L which were formed in the U-ing operation.

The mechanical properties of the final plate are given in Table 7. The differences between the location of the original side of the U and the rounded part of the U seem to have disappeared. The properties of the formed pipe meet the 30,000 psi yield strength specification value of ASTM B-168 and the required 27,000 psi 600° F yield strength on which the 20,000 psi allowable stress at 600° F is based.

Microstructural Changes Due to the Heating Cycles

Samples for metallographic study were removed from the end of each tensile test bar. Referring to Figs. 8 and 9 and then to Figs. 14 to 16, it is interesting to note that the photomicrographs of the samples which were just subjected to a heating cycle showed a more rapid response in their grain growth than those removed from the hot-worked samples. In these photomicrographs one can also follow the gradual change of recrystallization as the original grain boundaries are slowly dissolved and new large grains with pronounced grain boundaries are developed. Though grain growth and carbon solution occurred in both cases, the effects are not as pronounced in the hot-worked samples as in the samples which were solely heated to the forming temperature. Figure 16 shows the structure of the finished pipe taken at a random location.

Welding of Pipe

The longitudinal seam of the weld of that pipe was made entirely with inert-gas processes shielded with argon. The first passes were made using the tungsten-arc process with the filler wire fed in by hand. Subsequent passes were deposited by the semiautomatic gas-shielded-arc consumable-electrode process. The consumable insert was flattened INCO "62" wire which was tack welded at 2-in. intervals. The weld preparation is shown in Fig. 17 and the welding procedure (MWP-1604-P, Rev. 2) is given in Appendix A.

The cleaning operation of Inconel weld deposits is extremely important for the production of sound welds. To assure consistent wetting of the liquid weld metal with the solid deposit or base metal, it was stipulated that no cleaning could be done in the same area at the time of welding so that the dust settling on the welds would not interfer with successful welding. The mechanical properties of the wire deposit are also given in Table 8.

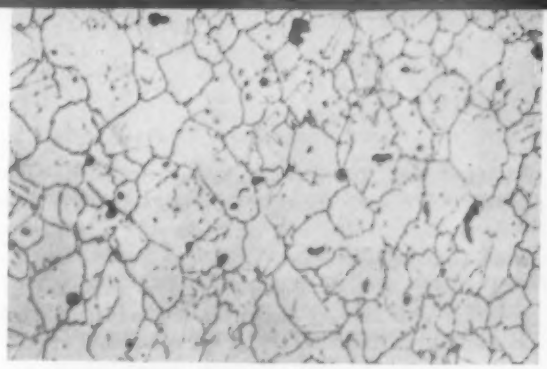


Fig. 14—Photomicrograph of specimen taken from hot-worked sample. Specimen No. 518; etchant 10% NaCN. X 100

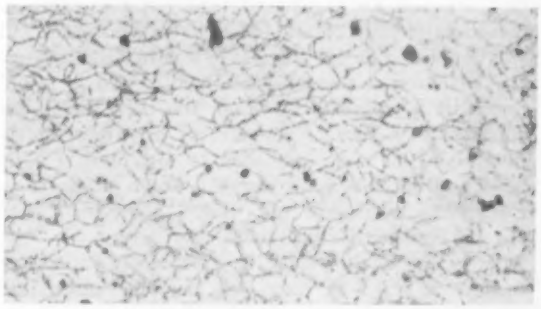


Fig. 15—Photomicrograph of specimen taken from hot-worked sample. Specimen No. 524; etchant 10% NaCN. X 100

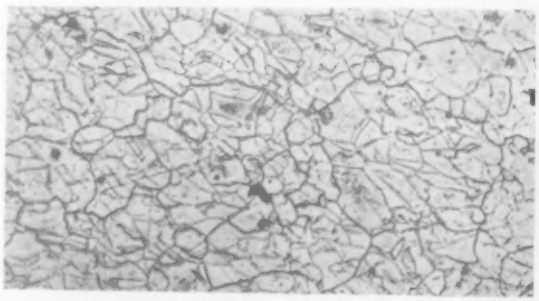


Fig. 16—Photomicrograph of structure of finished pipe. Specimen No. 528; etchant 10% NaCN. X 100

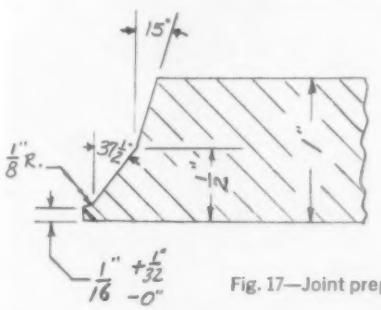


Fig. 17—Joint preparation

Quality Assurance of Welded Pipe

The specification of the welded pipe required that the quality assurance provisions for welded austenitic chromium-nickel alloy steel pipe (ASTM A358-56T) be met. Full size pipe sections were

flattened and no fissures were detectable. The range of specimens which were tested are shown on Fig. 18.

Nondestructive Inspection

1. *Dye Penetrant Inspection.* Dye penetrant inspection was carried out after 1st and 4th pass in addition to the inspection of the completed weld.

2. *Ultrasonic Tests.* Both shear wave and longitudinal wave technique were used. The shear wave testing was carried out in accordance with MIL-Standard 271 which specifies that welded pipe be inspected for transverse type defects. Due to considerable difference in attenuation the instrument was calibrated on a 3% notch in the weld metal when the weld metal was checked, and again on a 3% notch in the base metal when the base metal was checked. By way of comparison when the instrument controls were adjusted to obtain a $2^1/_4$ in. height obtainable from the 3% notch in the base metal, the maximum pip height obtainable from the 3% notch in the weld metal was $^1/_2$ in.

In longitudinal testing the instrument was calibrated on a $^1/_4$-in. diam flat bottom hole drilled 0.030 in. deep on the inside of the pipe. Again illustrating difference in sonic penetration, when checking base material the third back reflection had a height of $2^1/_4$ in.; when the crystal was placed on the weld metal, the third back reflection was only $1^3/_8$ in. high.

Fig. 18—Specimens meeting requirements of ASTM A358-56T

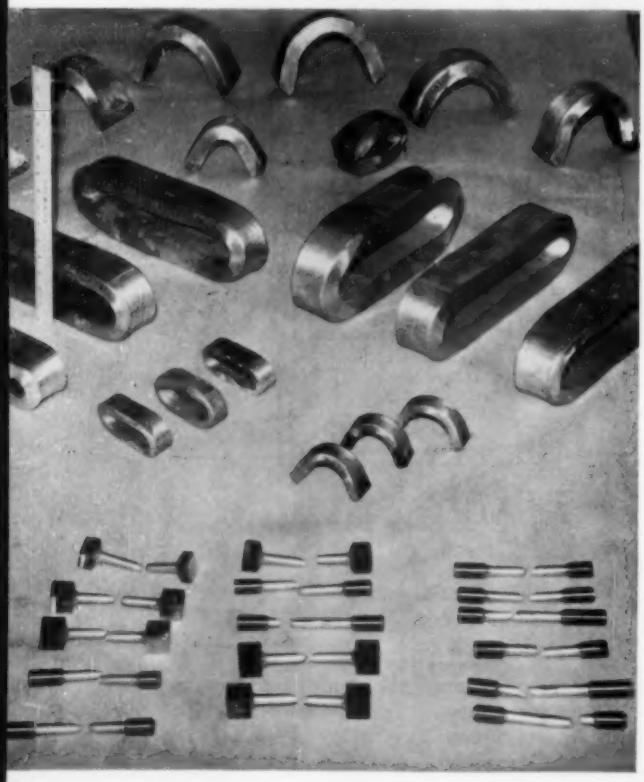


Fig. 19—Weld defect resulting from insufficient cleaning

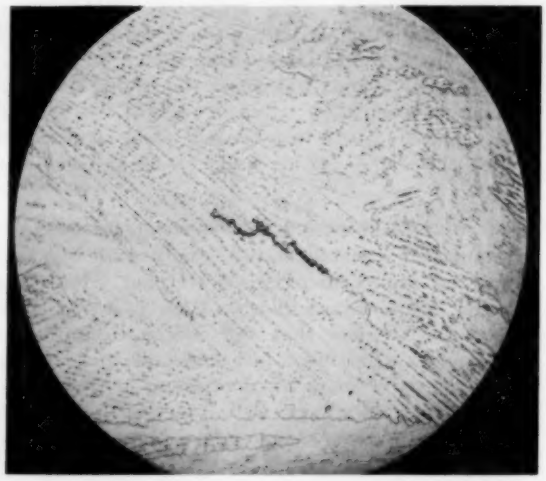


Fig. 20—Fissure in weld deposit

The pipe was found to be free of rejectable indications in both shear and longitudinal wave testing.

Radiography

Radiographs of the longitudinal weld of the surveillance pipe were interpreted to water clear standards—that is, the welds were supposed to be entirely free of discontinuities. Radiographs on Eastman Kodak AA film were difficult to interpret to such stringent standards at a 2% sensitivity level. The large grain size of the weld deposit caused a mottled effect on the film. This phenomenon is caused by diffraction of the x-rays and interferes with the interpretation of the radiograph.

The condition was somewhat ameliorated by the use of the fine grain Eastman Kodak M film. These radiographs showed up the 1% penetrameter. However, it is evident that evaluation of radiographs of Inconel weldments to water clear standards presents a problem.

To determine the type or types of imperfections in the weld sections which from the radiographs appeared to contain discontinuities were cut out and metallographically inspected. Out of six ques-

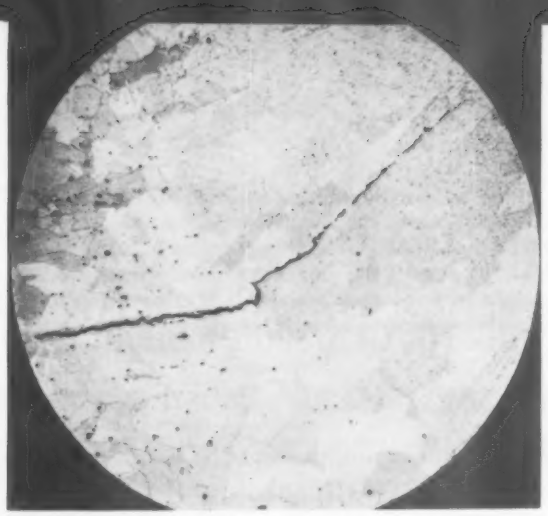


Fig. 21—Weld defect resulting from fissure in weld heat-affected zone

Fig. 22—Base-metal segregate fissures

tionable locations, three were found to contain defects in the weld. Figure 19 shows a defect in the weld deposit believed to be due to insufficient cleaning between passes. Figure 20 shows a fissure in the deposit, while Fig. 21 presents a defect in the weld deposit originating from a fissure in the weld-affected zone; such heat-affected zone fissures associated with a segregate region of the base metal were found in the other three locations.

These base metal segregate fissures—Fig. 22—are aligned parallel to the plate surface. They are limited apparently only to that portion of the weld heat-affected zone which reaches a temperature high enough for recrystallization and grain growth to take place. The fissures are not considered serious because of their small size and parallel alignment with the plate surface.

Base Metal Fissuring in the Weld Heat-affected Zone

Until recently fissures in Inconel weld heat-affected zones were not known. This and other work however, have shown that such fissures occur. The distinct causes of that base metal fissuring have not been established, although an emission spectroscopical study suggests that the fissured region is enriched in chromium by a small amount and depleted in iron. X-ray diffraction studies on samples removed by micro techniques did not yield interpretable results. The lines could not be correlated with any known solid solution or carbide lines of nickel or chromium, but rather with silicates.

Efforts are now directed toward determining the nature of the segregate so that it can be eliminated. Welding studies on sections of that plate showed that fissuring is only observed when using the inert-gas-shielded metal-arc process and not when using the tungsten-arc process or when welding with coated electrodes. From the review of a multitude of other Inconel welded specimens, it appears that neither the tungsten-arc nor the coated-electrode process is liable to cause such fissures.

The observation that the segregate may contain silicates in an amount which makes the percentage of silicon higher in the segregate region than in the base metal, might be a valuable clue explaining the fissuring. Pease[2] states, "Nickel-chromium bearing alloys seem to be more susceptible than other high-nickel alloys to hot cracking when other elements, notably silicon, are present. The hot-cracking susceptibility of a nickel-base alloy weld metal, for instance, with 15% of chromium, is sharply increased as the silicon content increases from a few tenths of a percent to 1% and higher, while levels of the order of 1% are relatively innocuous in nickel and nickel-copper alloys."

Conclusion

This paper covers the fabrication of a pipe by a specific process. Hence, the mechanical test results reflect only those process variables—time, temperature and deformation—which were considered of importance to assure an acceptable pipe.

It should be recognized that the forming of a 10-in. pipe from a 1-in. plate cannot be compared to a forging operation which requires heavy breakdowns. Therefore, the data developed in this investigation should be interpreted to apply only to jobs which are produced by light reductions. Thus, the whole heating and forming cycle has to be predicated upon the fact that there does not exist a final operation which can be considered a heavy enough reduction to raise the mechanical properties by hot-cold work.

To be sure that the minimum mechanical properties are obtained in a forging, the forging or forming operation has to be so divided that the final deformation or reduction, possibly of 20% or greater, can be performed within the temperature range of 1600 to 1850° F. In that temperature range—particularly at the lower end—the alloy is sufficiently cold-worked to re-establish the mechanical properties.

The quality of an Inconel weld deposit made by the gas-shielded-arc consumable-electrode process has not reached that level that a water-clear and

thus indication-free radiograph is obtainable. In gas-shielded-arc consumable-electrode welds there is a sufficient number of imperfections which make a radiograph difficult to interpret. These imperfections are usually not large enough to produce a sharp image on the film. Still they produce enough of a variation of density on the film to make interpretation difficult.

There exists evidence today that some quality of the base metal, which in this specific case is seen as streaks of segregates, adversely influences the quality of weldments produced by the gas-shielded-arc consumable-electrode process. Experience seems to indicate that the heat-affect zone is not likely to fissure in the tungsten-arc process or when using the covered electrode.

Pipe welded by the gas-shielded-arc consumable electrode meets the quality requirements as established by ASTM for high-temperature piping. However, because of the difficulties of interpreting radiographs to water-clear standards, it might prove to be more economical to substitute tungsten-arc welding.

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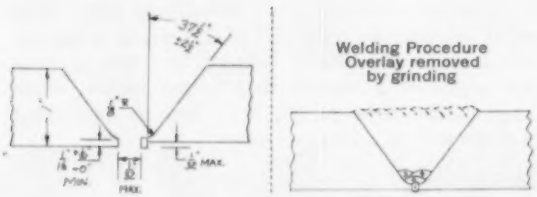
Acknowledgment

This work was done for the United States Atomic Energy Commission under Contract No. W-31-109-Eng. 52.

APPENDIX A

MWP-1604-P, Rev. 2
WELDING PROCEDURE FOR INCONEL PIPE

Joint Geometry



Scope: Welding procedure for seam weld in Inconel pipe.

Material: Nickel-chromium-iron (Inconel) per KAPL Specification KPM3-47 dated Aug. 4, 1958.

Procedure and Performance Qualification: Welding procedure and welders to be qualified per Section IX ASME Boiler and Pressure Vessel Code.

Welding Position: Flat.

Removal of Scale and Oxides: Scale and oxides adjacent to the welding groove shall be removed by grinding to a minimum of 3/4 in. either side of groove. Grinding shall be accomplished by use of either aluminum oxide or silicon carbide wheels.

Cleaning (Prior to Welding): Weld groove and adjacent surface must be cleaned with acetone or equivalent to insure complete removal of possible contaminates. Following cleaning, weld groove will be dye-penetrant inspected.

Positioning Consumable Insert: Consumable insert will be tacked at 2-in. intervals. Pipe is purged with Argon to insure tacks do not scale on inside surface.

Operating Data: Tungsten Inert Gas.

Electrode: 1/8 in. diam 2% thoriated tungsten.
Wire: ASTM B304-56T (Class ERN 62).
Torch shield: Argon—25 cfh.
Internal shield: Argon—5 chf.
Current: dc.
Polarity: straight.

a. Current for first pass (fusion of insert)—95 amp.; Voltage for first pass—22 v.
b. Current for second pass (adding 3/32 in. Inconel "62")—115 amp.; Voltage for second pass—24 v.

Operating Data: Metal Inert Gas.
Current, direct; polarity, reverse

Rod size, in.	Voltage	Amperage	Travel, ipm	Shielding gas	Gas flow, cfh	Wire feed control, ipm
1/16	32	200	12	Argon	50	35
0.045	29	230	12	Argon	50	53

Arc Length: 1/4 in. maximum. *Width of Bead:* 1/2 in. maximum. *Depth of Bead:* 1/8 in. maximum. *Nozzle Size:* 8. Preheat: None; unless the material is below 60° F—then preheat between 60 and 85° F.

Cleaning of Weld Deposit: Each weld pass shall be wire brushed to remove surface oxide and discoloration. Stainless steel brushes shall be used for this operation. Starts and stops shall be staggered on successive passes. No peening of weld shall be allowed. Maximum interpass temperature 250° F. All welds shall be smooth and show a workmanlike appearance.

Radiographic Interpretation: Radiographs will be interpreted to ASME Boiler Pressure Vessel Code requirements.

Sequence of Weld Inspection:

A. Dye-check no later than third pass.
B. Radiograph complete weld following final forming operation.
C. Dye-check complete weld inside and outside after final forming operation.

Enclosed Welding

Technique Applied to Welding of Reinforcing Bars

for concrete structures indicates potentials for other applications as a result of original investigation and a review of selected literature

BY W. P. CAMPBELL

ABSTRACT. An investigation was conducted to evaluate the suitability of "enclosed" welding for the butt welding of steel reinforcing bars used in concrete construction. This technique was developed initially for the butt welding of rail sections.

Welds were readily produced with satisfactory appearance and soundness. The tensile properties of the joints were approximately equivalent to those of the unwelded bars. Rather variable results were obtained when joints were bent as required by the specification covering the reinforcing bar, and thus bending of joints after welding should be avoided.

The welding time was much shorter than that required for conventional metallic arc welding; thus savings should result with the enclosed technique. AWS E7016 electrodes are suitable for this application if the hydrogen available from the coating is reasonably low.

Enclosed welding merits consideration for making other types of joints where a simple and rapid technique is desirable.

Introduction

Butt welding of small diameter steel bars by the manual metallic arc-welding process is one of the more difficult joining operations. This is due primarily to the fact that the weld joint does not provide much support for the weld beads. Thus the operator must make and break the arc frequently due to the short bead length and to the necessity for avoiding too large a weld puddle which would run out of the joint. Considerable care is needed to obtain complete fusion and to avoid excessive slag inclusions and porosity. The technique requires several small, short beads with good slag removal after depositing each bead. For single bevel joints, a backing for somewhat less than one-half of the weld may be used to advantage. Satisfactory welds can be made, but the joining operation requires considerable skill and is time consuming.

Reinforcing bars for concrete structures are being welded with increasing frequency. It is often advantageous to butt weld standard length bars in new structures or to attach a bar to one already in place when a concrete structure is being extended. For example, in the construction of reinforced concrete arched roofs of several aircraft hangars, it was necessary to butt weld bars after they were placed in the main beam forms. Welding was done with low-hydrogen type electrodes to deposit metal in the flat position into a single bevel joint having a partial backing. During the construction program, several sample welds were prepared by the welding operators and subjected to tensile testing. There was considerable variation in weld quality, and the lower strength fractures were associated with weld defects such as lack of fusion, porosity and slag inclusions. It was evident that welding operators did not find this an easy joint to make satisfactorily. However, when the samples broke well outside the weld or in the weld without too great a

Reinforcing bar test assembly prior to welding

W. P. CAMPBELL is Senior Scientific Officer, Mines Branch, Dept. of Mines and Technical Surveys, Ottawa, Canada.

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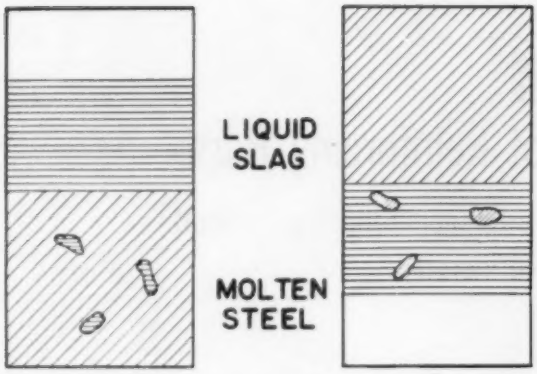

Fig. 1—Equilibrium states of molten steel and liquid slag with nonbasic electrodes (A) and basic electrodes (B)

strength reduction or visible evidence of weld defects, the operator who had prepared the samples was permitted to weld bars in the structure.

The fact that welding of reinforcing bars is of interest is illustrated by an article[1] in the WELDING JOURNAL and also by a bulletin[2] issued by the Bridge Division of The Texas Highway Department. Several requests for information on the subject have been received by the Welding Section, Physical Metallurgy Division, in recent months.

Three articles[3–5] in technical publications prompted a short investigation to assess a different technique for the welding of reinforcing bars. These articles described a technique developed for welding of rail sections and which is termed enclosed welding.

Basis of Enclosed Welding

Enclosed welding as a term is descriptive since the joint is partially enclosed by a copper block or blocks which retain the molten weld metal but let excessive amounts of slag escape through a slight gap between the joint area and the copper block or blocks. The parts being joined must be placed in or near the horizontal position to permit downhand welding. A welding electrode—either $^3/_{16}$ or $^1/_4$ in. in diam, depending upon the size of the joint—is then inserted through the open top of the enclosure and high currents are used to produce a large pool of molten metal. In effect, the welding operation is a rapid continuous casting process.

The articles on enclosed welding[3–5] stated that the success of the technique depends upon the use of basic or low-hydrogen type electrodes. As illustrated in Fig. 1A, slag may be present in the steel when nonbasic electrodes are used. On the other hand, Fig. 1B shows that, when basic electrodes are used, slag will not be present in the steel but instead some steel may be present in the slag.

The enclosed welding technique was developed by The Welding Department, Philips Research Laboratories, Eindhoven, Netherlands, in a program of research to develop an improved method for the butt welding of rails *in situ*. The technique was reported to be successful as judged by sectioning, pulsation fatigue tests, and a type of drop-weight test called a tup test. As of October 1958, many thousands of welds in rail sections had been made. British Railways were reported to have used the technique on branch and main lines. Special, extra-low-hydrogen electrodes were developed by Philips, because it was observed that the hydrogen from the standard low-hydrogen electrodes caused excessive porosity in rail section welds. One of the articles[4] contained the statement that "Suitable enclosures can equally well be designed for other cross sections; among the enclosures designed is one for rods of circular section such as used for reinforcement of concrete."

Investigation

The investigation included the development of a technique specifically for deformed type reinforcing bars and evaluation of the technique by visual, radiographic and metallographic examinations and by tensile and bend testing.

Materials

All welds were made in a No. 9 reinforcing bar (1.128 in. nominal diam) having the chemical composition and mechanical properties shown in Tables 1 and 2.

The initial tests were made with $^3/_{16}$-in. diam AWS E12016 electrodes, but most tests were made with $^3/_{16}$-in. AWS E7016 electrodes. Diffusible hydrogen as determined by the glycerine displacement technique was about 0.007 cm^3 and 0.06 cm^3 per gram of deposited weld metal for the E12016 and E7016 electrodes respectively.

Procedure

The bars were cut at right angles, usually by sawing, but for some tests, by flame cutting and then assembled in the copper enclosure block as shown in the lead photograph.

Table 1—Chemical Composition

	Percent
Carbon	0.40
Manganese	0.60
Phosphorus	0.005
Sulfur	0.026
Silicon	0.16

Table 2—Mechanical Properties

	Determined on bar (avg of three)	ASTM A15-58T for intermediate grade deformed bars
Ultimate tensile strength, kpsi	78.6	70.0–90.0
Yield, kpsi	49.7	40.0 min
Percent elongation in 8 in.	23.6	11 min

Preliminary tests were made with a smaller block. Although the initial welds were of satisfactory quality, it was evident that the block deteriorated with fair rapidity due to overheating. Thus the second block shown in the lead photograph contains a greater mass of metal at the lower side of the joint. It was prepared by machining a hole eccentrically in a $2^1/_2$ in. long and 3-in. diam round bar and then cutting the unit in half. For ease of removal, as when joining long lengths, the block is split along a vertical plane and has two steel alignment pins running horizontally through the bottom portion. It is probable that these pins could be omitted since a C clamp will hold the two halves of the enclosure with sufficient accuracy.

Following the recommendations in the articles on enclosed welding, the first enclosure block was made so that there was a slight gap between the inner surface and the deformations on the bar. However, the enclosure in the lead photograph was made to fit approximately in contact with the outer contour. A $^3/_8$ in. spacing between the ends of the bars was used for most of the tests, although preliminary welds were made with wider spacing. When the $^3/_8$ in. spacing was used, the entire weld could just be made by consuming one 14-in. electrode whereas with the larger spacing an electrode change was necessary.

Alternating current is said to be preferable for enclosed welding of rail sections.[4, 5] Consequently, welds were made with both the E12016 and E7016 electrodes using alternating current. Because the direct-current welding machine is used extensively at construction sites, welds were also made with the E7016 electrode using direct current and electrode positive. The final selection of current values was left to the welding operator. Most welds were made using about 200 amp alternating current with the E12016 electrode and about 260 amp, either alternating or direct current, with the E7016 electrode.

Welds were evaluated initially by appearance. Some radiographic inspection and weld sectioning were done when the weld appearance indicated that the operator had developed the welding technique so that no difficulty was encountered in producing welds free of gross defects such as lack of fusion, surface porosity or inadequate weld section. Tensile and bend tests were then made on several welded joints. No grinding or other machining was done on the samples. The tensile tests were made by breaking the entire cross section and the bend tests were made by bending the bars around a former having a diameter of 5 in., through 90 deg, or until fracture occurred if at less than 90 deg.

Results and Discussion

The visual appearance of typical butt welds is shown in Fig. 2.

The bars were placed in the enclosure block so that the longitudinal ribs were at the top and bottom in order to avoid any interference with the molten slag flow while filling the joint. As is evident in Fig. 2, welds of quite satisfactory visual appearance can be produced. Some copper pickup from the enclosure block invariably occurs on the bottom surface of the weld, but metallographic examination did not reveal any penetration of copper into the weld. In order to achieve welds such as shown in Fig. 2, the welding operator found it necessary to weave the electrode across the joint gap in a direction perpendicular to the longitudinal axis of the reinforcing bar. There was a momentary pause at the outer ends of the weave pattern. Without this motion, there was a tendency for one or both sides of the joint to be concave and thus the weld cross section was reduced. The concavity coincided with a larger than normal accumulation of slag.

When the operator became accustomed to the weaving technique required, welds of satisfactory visual appearance were consistently made. The small amount of copper pickup from the enclosure block during production of several welds resulted in some deterioration in the root appearance of subsequent welds. This trend could be halted by smoothing the bottom of the enclosure block by filing and the use of emery cloth. No slag removal problem was encountered, because the slag accumulated chiefly between the two deformations adjacent to the weld and fell off the weld surface when the bar was removed from the enclosure block. Welding was continuous, and a joint was completed in about 1 min. It is to be noted that this is considerably faster than the welding of the same bar by the conventional stringer bead technique with the necessary slag removal between beads.

Figure 3 illustrates a macrosection through a typical weld. The fused area is quite narrow for about the bottom two-thirds of the joint and is

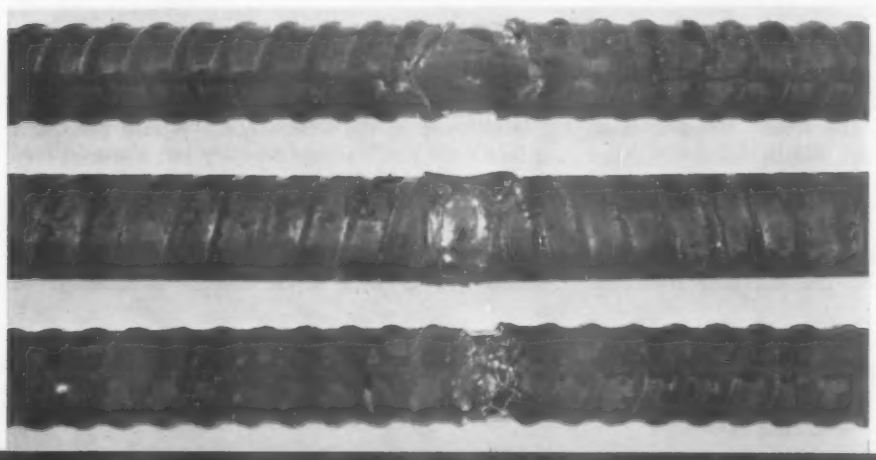

Fig. 2—Visual appearance of typical welds, showing bottom of a weld at bottom, side of a weld at center, and top of a weld at top

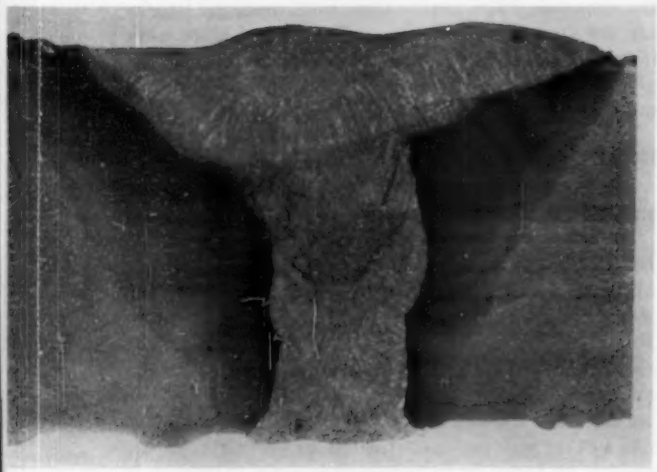

Fig. 3—Typical weld cross section, approximately X2

only slightly wider than the original $^3/_8$-in. joint gap. The upper one-third increases in width due to the increased heat build-up, the reduced mass of surrounding metal in the bar, and the necessity of building up some weld reinforcement in order to avoid a large crater effect and resulting defects. The weld deposits were sound, although a single spot of porosity was observed in the top portions of some welds. Radiographic examination of several joints verified that the technique could produce welds of satisfactory soundness. The microstructure of the heat-affected zone consisted of coarse grained ferrite and pearlite thus indicating an absence of hardening.

As stated earlier, the initial tests were made using $^3/_{16}$-in. E12016 electrodes. These electrodes were used because the literature references indicated that extra-low-hydrogen electrodes were necessary when welding rail sections. Electrodes having higher hydrogen-producing potential had been found to cause porosity in rail sections because a considerable volume of gas was produced in the large volume of molten metal inherent with the enclosed welding process.

When the initial tests with the E12016 electrodes showed promise, it was decided to conduct further tests with electrodes which more closely matched the reinforcing bar in mechanical properties. Consequently, all subsequent test welds were made using $^3/_{16}$-in. E7016 electrodes. The first three welds with E7016 electrodes were tested in tension, and the results indicated that this class of electrode should be satisfactory but that it would be advisable to reduce the coating moisture content. Fish eyes were observed on the fracture surface of the one sample which broke in the weld. Because these three tests were made with E7016 electrodes taken from open-shelf storage, it was decided that baked electrodes would be used for all subsequent tests. Consequently, the electrodes were baked at 500° F for 2 hr and then placed in a storage oven at 215° F. After this treatment, the diffusible hydrogen content was determined by the glycerine method and found to be about 0.06 cm^3 per g of deposited weld metal. This value is still about ten times greater than that obtained for the E12016 electrode. However, radiographic examination of eight welds made with the baked E7016 electrodes indicated that satisfactory soundness could be obtained.

The results of all tensile tests performed on welds are shown in Table 3. Also shown, for comparison purposes, are the tensile properties obtained on three unwelded bars and the minimum tensile properties specified for intermediate grade deformed bars to ASTM specification A15-58T.

The ultimate tensile values obtained for all the welded samples are equivalent to those obtained for unwelded bars with the exception of one joint which was welded with the E12016 electrode and which had a slightly lower ultimate tensile strength. The yield strengths of all E12016 welds were lower than those of both the unwelded bars and the joints made with the E7016 electrodes. Of the three joints which broke at the fusion line or in the weld, two had relatively low elongation values and one had a surprisingly high value. The elongation values for the E12016 welds were on the average slightly lower than those for the E7016 welds. With the exception of two of the three samples which broke at the joint, all welded samples exceeded the minimum mechanical properties specified for intermediate grade deformed bars to ASTM specification A15-58T.

Two of the samples which failed at the joint had elongation values less than the minimum required by the specification. In one of these samples, the failure was due to an unfused root, a type of defect which should be avoidable with practice. In any case, such a defect should be evident on visual examination and thus could be repaired by grinding the root and depositing a small bead of weld metal. The low elongation of the second sample evidently was due to excessive hydrogen in the weld resulting from the use of unbaked electrodes. It is believed that this type of failure can be avoided quite easily by using only properly baked and stored electrodes.

ASTM specification A15-58T states that deformed bars should be capable of withstanding without cracking a bend through 90 deg around a former which has a diameter five times that of the reinforcing bar. Consequently several unwelded and welded bars were subjected to this test. The welded joints were made with the baked E7016 electrodes. Unwelded bars passed the test consistently, but the welded bars showed variable results. Of three samples bent with the weld root in tension, one passed successfully, one failed by reason of a $^1/_8$-in. fusion line crack and the third failed by reason of a $^3/_8$-in. crack in the weld metal. A side bend and a face bend test were satisfactory but a second face bend test failed due to the appearance of a 1 in. crack at the fusion line. Thus the welded joint in this bar is more liable to failure in bending than is an unwelded bar. The presence of rather slight fusion line or weld metal defects is sufficient to

Table 3—Tensile Properties of Unwelded and Welded Reinforcing Bars

Description	Ultimate tensile, kpsi	Yield strength, kpsi	Elongation in 8 in., %	Remarks
Requirements of ASTM A15-58T for deformed, unwelded bar	70.0–90.0	40.0 min	11 min	
Unwelded bar, current investigation	78.8	49.5	24.2	
	78.5	49.6	23.5	
	78.6	50.0	23.2	
E12016 electrode, enclosed welds	79.0	44.0	18.0	All broke some distance from welds at punch marks made for elongation measurements
	78.9	43.7	18.0	
	78.0	43.3	16.0	
	79.5	44.0	20.0	
	79.5	45.0	17.0	
	75.1	45.6	6.0	Broke at fusion line with fracture starting at unfused root
E7016 electrodes from open storage, enclosed welds	78.8	48.6	19.4	Broke away from weld
	79.1	49.3	20.0	Broke away from weld
	78.0	49.4	10.2	Broke in weld with appearance of some fish-eyes
E7016 electrodes, baked and stored in electrode oven, enclosed welds	79.2	49.4	26.3	Broke at weld
	79.4	49.8	21.5	
	79.9	49.9	20.3	Broke away from weld
	79.6	49.6	20.3	

initiate cracking in bending at the joint. For this reason it would seem advisable to make welds in reinforcing bars at locations where subsequent bending would not be necessary. Undoubtedly this is not a serious restriction.

In the tests conducted, equivalent results were obtained with both saw-cut and flame-cut preparation of rod ends and with both direct and alternating welding current with E7016 electrodes.

Enclosed Welding Potentials

The enclosed welding technique should be applicable to the butt welding of many other sections. In most welds, it will be necessary to maintain a definite clearance between the parts being joined and the enclosure in order to permit escape of slag. This is in contrast with the welding of the deformed type reinforcing bar in which operation the deformations automatically provide adequate spacing for slag accumulation without interference with the weld shape. The current investigation has shown that standard E7016 type electrodes, when properly baked and stored, can produce welds of satisfactory soundness. With larger volumes of molten metal in thicker or larger parts being joined, it may be necessary to use electrodes having lower hydrogen-producing potential in order to avoid porosity.

Enclosed welding appears to be a very rapid and economical joining technique and merits consideration in many applications.[6] An advantage with the process is that the large volume of molten metal, as compared to that occurring in conventional welding, will retard the cooling rate of the heat-affected zone and thus will reduce hardening and possible crack formation in the hardenable grades of steel.

Conclusions

1. Enclosed welding provides a rapid and simple technique for the joining of reinforcing bar when placed in the horizontal position.

2. Low-hydrogen electrodes of the E7016 class are satisfactory for welding intermediate grade reinforcing bar provided the moisture content of the coating is kept low. Preferably, electrodes should be withdrawn from moisture tight cartons or from heated storage ovens.

3. Welds of good visual appearance and possessing a satisfactory degree of soundness are readily obtained.

4. Enclosed welds in reinforcing bar can be readily made and will be approximately equivalent in tensile properties to unwelded bar.

5. Small defects in the weld or at the fusion line have a pronounced detrimental effect upon the bending characteristics of the joints. Thus bending at the joint location should be avoided.

6. Tests with reinforcing bars indicate that the enclosed welding technique should be applicable to many other joints.

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5. Zoethout, G., "Enclosed Welding of Rail Sections," *Philips Tech. Rev.*, **20** (4), 94 to 100 (October 1958).

6. Clevers, J. A. N., and Stemerdink, J. W. A., "Enclosed Welding of Vertical Grooves," WELDING JOURNAL, **39** (3), 223–228 (1960).

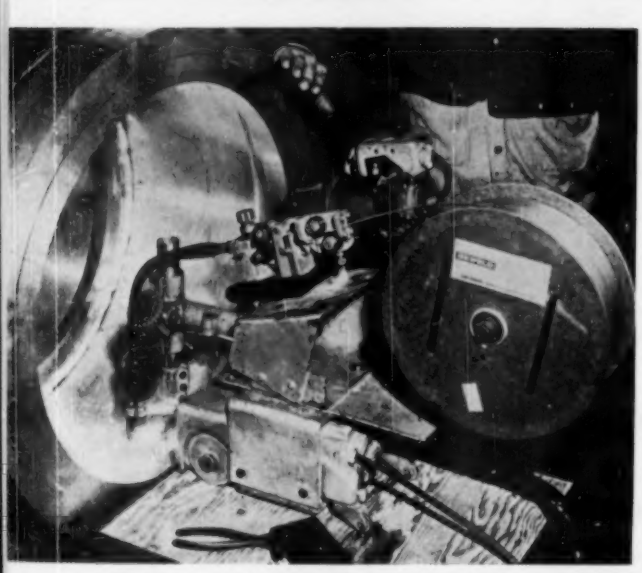


Fig. 1—"Square-butt" welding of $1^1/_4$-in. aluminum cylinder for nuclear industry at National Steel and Shipbuilding Co., San Diego, Calif.

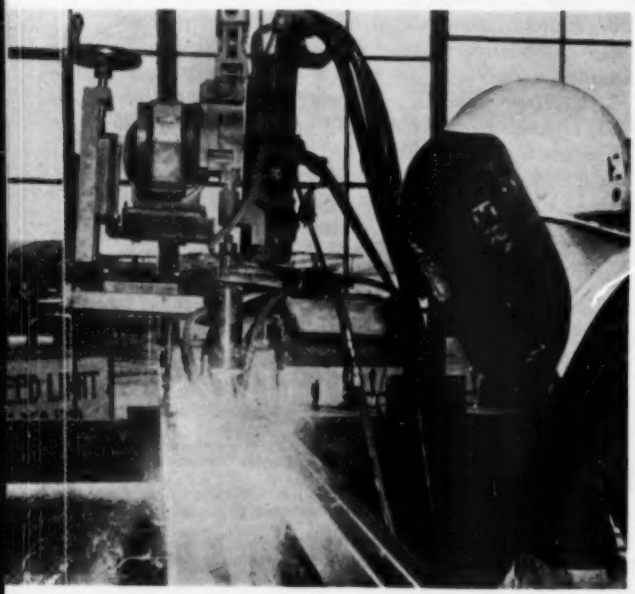


Fig. 2—"Square-butt" welding of heavy-wall aluminum cylinder at 8 ipm

Metalworking Progress Report:

Square-Butt Welding of Aluminum

Heavy-wall aluminum cylinders for use in nuclear industry are now being welded more economically, in fewer passes, with less total heat input, and at greatly increased speeds, thanks to a relatively new technique called "square-butt" welding.

National Steel and Shipbuilding Co., San Diego, Calif., achieves these startling results with metal arc welding equipment. Previous metal-arc welding of the $1^1/_4$-in. thick aluminum cylinders required: (1) preparation of open-vee beveled edges; (2) preheating with gas-welding torches to 350° F; (3) welding one side of the joint, then back-chipping and welding of the opposite side; and (4) several stringer-bead passes to complete the joint.

National Steel and Shipbuilding has eliminated vee-joint preparation, all preheating, back-chipping and stringer-bead passes with "square-butt" welding Only the simplest joint preparation is required: a clean, square, end-to-end joint. Where minimum weld reinforcement is desired, a shallow vee-joint may be used. Single-pass welds, one from each side, result in full build-up and penetration. Radiographic tests show 100% "water-clear" welds.

"Square-butt" welding, also known as "high-current" welding, is an engineering breakthrough which enables the welding of heavy aluminum plate at currents considerably above 400 amp. Prior to this development, attempts to exceed 400 amp resulted in arc instability, severe oxide folds between weld layers, and weld porosity.

"Square-butt" welding incorporates improvements in gas shielding and purity, wire quality and the slope-controlled power supply to overcome arc in-

Based on a story from the Linde Co., New York, N. Y.

stability. Single-pass, water-clear X-ray welds are the result.

High welding currents (up to 600 amp, DCRP) increase heat input at the weld zone and eliminate porosity, since the puddle remains molten long enough for porosity-forming gases to bubble out. Yet, the "square-butt" technique also reduces total heat input, since only one pass is required from each side, instead of several stringer-bead passes. The results are minimum distortion and reduced machining and scrap costs.

National Steel and Shipbuilding mounts 30-in. diam 6061 aluminum cylinders on a rotary positioner beneath a welding head. Joint edges of the $1^1/_4$-in. aluminum are square-machined for cleanliness, and incorporate a $^3/_8$-in. chamber, for minimum reinforcement. One-pass welds are made from each side at relatively low current (400 amp) and 27 v, DCRP, using $^3/_{32}$-in. diam aluminum wire. Argon shielding flow is 100 cfh. Water-clear X-ray welds are made at a speed of 8 ipm.

Severe operating conditions for nuclear process equipment demand that all welds be free of cracks, pits, inclusions or surface porosity. National Steel and Shipbuilding is meeting these high standards with "square-butt" welding at a remarkably low cost.

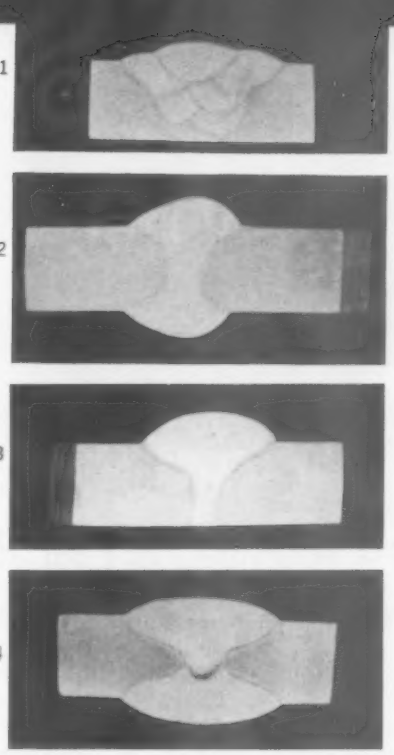


Fig. 3—Comparison of gas metal-arc "square-butt" welded joints(2, 3 and 4) with conventional "vee" joint (1); welds 1 and 3 were made using copper backing strip

Cut-Down Reducer Adapts Old Pipe to Modern Valve

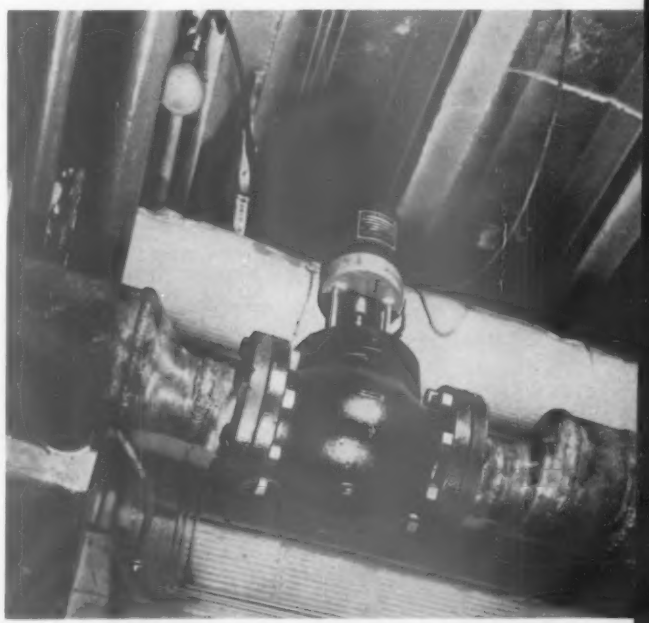
Saving of a half-day's welding and fitting time in revamping an old steam heating system in Louisville, Ky., has been credited to the uniformity and adaptability of a line of welding fittings that were not even produced in America when the original piping was installed.

The job was to install a 4-in. motorized valve in existing 7-in. carbon steel piping. The problem was that 7-in. pipe is an obsolete size, not matched by any present-day reducer.

The solution was to flame-cut and bevel the large ends of two 8- x 4-in. eccentric reducers at the proper point on their eccentric conical sections, weld the cut-down reducers to the old-size pipe, add welding neck flames and mount the flanged valve.

Location of the job—a conversion to oil-and-gas-fired boilers—was the 35-yr-old regional headquarters building of the Federal Land Bank. Charles Wingfield, job superintendent for Comley-Bushfield Co. Inc., Louisville contractor, said uniform wall thickness and true circularity made it possible to cut the eccentric reducers at the desired point and achieve a perfect match with the obsolete size of pipe. The installation took a welder and a fitter less than half a day. An alternate method, "orange peeling" the old pipe down to 4-in., would have taken a full day, he estimated.

Based on story from Tube Turns Division, Chemetron Corp., Louisville, Ky.



Cutting down standard 8 x 4 in. eccentric reducers at the proper point on their eccentric conical sections saved half a day over alternate methods of fitting this 4-in. motorized valve to an obsolete size 7-in. pipe in revamping the heating system of a 35-year-old Louisville, Ky., building

Society News

Highest Attendance Ever Recorded for AWS Welding Show

Annual Meeting Features Variety of Technical Papers on Welding Developments Around the World

Welding Show at Coliseum opened with chain-cutting by Mlle L. Blosset of France with an assist by President-elect A. F. Chouinard

Attendance at the American Welding Society Exposition set an all-time high of 19,125 at the Coliseum in New York, April 18–20. Visitors were exposed to $3 million worth of welding and allied equipment presenting the latest developments in welding technology.

During the week of April 17–21, a total of 1713 persons registered at the Hotel Commodore for the 42nd AWS Annual Meeting. The essence of international cooperation occurred as members of the International Institute of Welding comprising representatives of 28 countries gathered to read technical papers and attend presentations by American welding scientists and engineers.

Crowds at registration desk of the AWS Welding Show on Monday, April 18th. Total attendance of more than 19,000 was recorded

This year's meeting was unique in that it coincided with the first IIW Annual Assembly to be held in the United States. The IIW delegates met during the week of April 10–15 at the Hotel Sheraton-Atlantic in New York. Delegates who attended both meetings represented Argentina, Belgium, Canada, France Germany, Great Britain, Japan, Norway, Netherlands, Poland, Sweden, Switzerland, Turkey, USSR and many other countries.

Opening Session

Convention Chairman J. E. Dato called the opening session of the Annual Meeting to order at the Commodore Hotel and President R. D. Thomas, Jr., greeted members and their guests. President Thomas addressed the audience and stressed the importance of America's participation in the IIW. He pointed out that we in the United States are reluctant to join in the establishment of international codes and standards, preferring to remain aloof and independent. "American isolation," he said, "both political and technical, is at an end. Our ability . . . becomes ever so much greater through the collaboration of others with similar objectives. As today's combined efforts speed our success, so shall tomorrow provide a better standard of living for all the peoples of the world." (The full text of President Thomas' address appears on pages 640–647).

Annual Awards Presented

Following the opening address by President Thomas, several awards

were made to persons making outstanding contributions to welding and to the SOCIETY.

District Meritorious Awards, given in recognition of loyalty and devotion to the affairs of the SOCIETY, were given to J. N. Alcock, J. B. Austen, W. T. DeLong, R. W. Emerson, J. J. MacKinney, A. R. Meyer, I. A. Oehler, J. E. Riley, R. L. Townsend, C. M. Underwood and S. T. Walker. Three other award winners not present at the meeting who will receive awards at future section meetings are: F. E. Garriott, R. Gilbert and M. A. Levinstein.

Established last year, the Adams Memorial Membership Awards for teaching activities which are considered to advance the knowledge of their students in welding were given to W. H. Munse, University of Illinois, and W. E. Savage, Rensselaer Polytechnic Institute. R. C. Wiley, California Polytechnic Institute, who was not present at the meeting, will also receive the award.

Dr. G. E. Claussen, director of research, Arcrods Co., and H. E. Miller, manager, Welding and Brazing Section, Manufacturing Process Development Dept., Carrier Corp., each received a National Meritorious Certificate Award in recognition of their counsel, loyalty and devotion to the affairs of the SOCIETY, their assistance in promoting cordial relations with industry and with other organizations and their contributions of time and effort in behalf of the SOCIETY.

Honorary membership in AWS is recommended by the Society's Honorary Membership Committee and voted unanimously by the Board of Directors. It is bestowed upon persons of acknowledged eminence in the welding industry, or those who may be accredited with exceptional accomplishments in the development of welding science. This year H. E. Rockefeller, general manager, Electric Welding Dept., Linde Co., Union Carbide Corp. and AWS treasurer was awarded this high honor by the SOCIETY.

Smiling presidents—President-elect Al Chouinard receives the president's gavel from President R. D. Thomas, Jr.

An Honorary Membership certificate presented to H. E. Rockefeller by President Thomas on behalf of AWS

Annually, three awards of Davis Silver Medals are given to authors whose papers are published in the WELDING JOURNAL in the areas of Machine Design, Structural Design, and Maintenance and Hard Surfacing. Co-authors of the best paper on Machine Design who received Silver Medals are A. L. Cooper, supervisor, manufacturing engineering, Westinghouse Electric Corp. and W. H. Morse, manager, a. c. motor and generator engineering, Westinghouse Electric Corp. Top paper award in the Structural Design category went to C. A. Zwissler, welding engineer, Fabricating Div., Kaiser Steel Corp.; and in the Maintenance and Hard Surfacing division, M. Friedmann received a Davis Medal for his outstanding paper.

Each year the Lincoln Gold Medal is awarded to the author who singly presents a paper which is judged to be the greatest original contribution to the advancement and use of welding published in an issue of the WELDING JOURNAL during the calendar year prior to the AWS Annual Meeting. The award, sponsored by James F. Lincoln, chairman of the board of the Lincoln Electric Co., was given to J. Heuschkel, manager, Metals Joining Section, Westinghouse Research Laboratories, for his paper "Weld Metals in Nickel-Base Alloys," published in the June 1960 issue of the WELDING JOURNAL.

M. D. Stepath, president, Arc-Air Co., was awarded the Samuel Wylie Miller Medal in recognition of his meritorious achievement in welding as inventor and developer of the process of back-gouging welded seams, removal of risers and repairs

R. T. Weil, Jr.

R. D. Thomas, Jr.

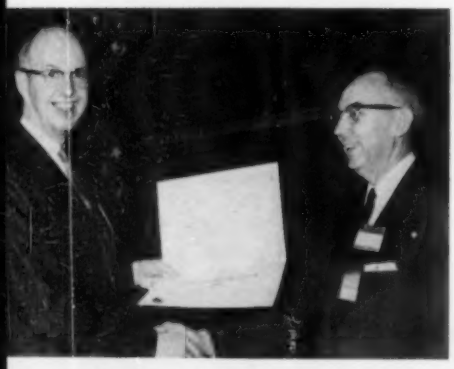
J. E. Dato

H. P. Granjon

Left: Certificate and medal presented to M. D. Stepath, winner of the Samuel Wylie Miller Memorial Award, by President Thomas. Right: J. F. Lincoln Gold Medal given to J. Heuschkel by President Thomas

Two of the Davis Silver Medals awarded by President R. D. Thomas, Jr., to W. H. Morse, left photo, and A. L. Cooper, right photo

National Meritorious Certificate Award presented on behalf of the SOCIETY to G. E. Claussen by President Thomas



Also a recipient of the National Meritorious Certificate is H. E. Miller who receives the award from President Thomas

to castings in a more economical way.

New Officers

New officers and members of the board of directors were announced by National Secretary F. L. Plummer. Elected president of the SOCIETY was A. F. Chouinard; and vice presidents Jay Bland, J. H. Blankenbuehler and C. E. Jackson.

President-elect Al Chouinard, who assumed office officially on June 1st, received the gavel, symbol of his new post and then made a few remarks in acceptance of the office. C. I. MacGuffie, an AWS past-president, gave a past-president's certificate, pin and life membership card to R. D. Thomas, Jr.

This year's newly elected directors-at-large are: J. E. Dato, A. N. Kugler, T. E. Jones and E. C. Miller. New district directors are: C. L. Kreidler, District 2; P. J. Rieppel, District 5; G. O. Bland, District 8; and W. J. Erichsen, District 11.

The National Nominating Committee, in addition to R. D. Thomas, Jr., chairman, will consist of C. I. MacGuffie, C. Becker, A. E. Pearson and the district representatives: G. W. Kirkley, James Cameron, D. Peterson, R. E. Lorentz, Jr., R. J. Yarrow, Keith Sheren, C. K. Seitz, C. R. Reardon, D. J. Middlehurst, J. B. Ross and R. E. McCormick.

At the Annual Meeting, President Thomas introduced Walter Edstrom, president of the IIW who made a few brief comments. Prof. R. T. Weil, Jr., vice president of the American Institute of Electrical Engineers, who gave highlight announcements about AIEE programs and appropriate acknowledgments of assistance of AIEE Associates. Several technical papers at the AWS Annual Meeting on electric-arc welding were sponsored by AIEE.

Adams Lecture

Presented annually in honor of the SOCIETY's first president and founder Dr. Comfort A. Adams, the Adams lecture covers work done by an outstanding engineer, scientist or educator. Henri Granjon, chef de service of the Institut International de la Soudure in Paris, France, presented the lecture called "Studies on Cracking and Transformation in Steels During Welding," a result of the work done in conjunction with Commission IX of the IIW. Granjon was presented a certificate and honorarium after his very informative lecture, by President R. D. Thomas, Jr.

President's Reception and Banquet

The spacious Windsor Ballroom at the Hotel Commodore was jammed for the President's Reception.

Left: Past-president C. I. MacGuffie presents a life membership in AWS to President R. D. Thomas, Jr.

Right: JOURNAL Editor T. P. Schoonmaker instructs authors at early breakfast

Two recipients of Adams Memorial Memberships are W. H. Munse, left photo, and W. F. Savage, right photo. This award, being pesented by President Thomas, is given to educators who advance the teaching of welding

Don Middlehurst, right, presents a check from the Houston Section for the UEC Building Fund to A. F. Chouinard

Guests were greeted by national officers and staff members. Following the reception, the Annual Banquet was held in the Grand Ballroom where more than 600 persons (a record number) enjoyed a fine dinner and professional entertainment.

Technical Program

During the Annual Meeting week more than 70 papers in 22 sessions were presented. Several papers were presented by IIW members covering processes, welded structures and weldability. AIEE-sponsored papers were in the areas of resistance and arc welding. Other papers were presented on alloy fabrication, brazing, electroslag welding, arc-spot welding, nuclear components, submerged-arc welding and gas shielded welding.

Plant Tours Popular

Turnout for tours on Tuesday, Wednesday and Thursday was large as participants went by bus to Worthington Corp., the Buick, Oldsmobile, Pontiac General Motors Assembly Plant in Linden, N. J., Linde Co. Development Laboratory, International Nickel Co. Research Laboratory and Electrode Production Plant, Republic Aviation Corp., Farmingdale, L. I., N. Y., and the Grumman Aircraft Engineering Corp.

Ladies' Program Enjoyed

Starting each morning with a coffee hour at the Hotel Commodore, the ladies' activities ranged from tours of New York's well-known sights such as the Empire State Building and Rockefeller Center to a breakfast and fashion show at B. Altman & Co. The latest spring fashions attracted many shoppers to the numerous stores on and near Fifth Avenue. Arrangements for the Ladies' Program were organized by co-chairmen H. C. Cook and J. W. Flannery.

Welding Show Hits Peak

The Annual Exposition was opened with a chain-cutting ceremony in which Mlle. L. Blosset of the French Institute of Welding wielded a cutting torch assisted by President-elect Al Chouinard. President R. D. Thomas, Jr., IIW President Walter Edstrom and National Secretary F. L. Plummer were among the officials at the Coliseum during the opening ceremonies on Tuesday morning.

The official attendance figure for the three-day exposition was more than 19,000. Visitors saw demonstrations of new products and processes by welding-products manufacturers.

Exhibitors are reported to have been swamped with inquiries about their products.

Welding Square Named

Marking the opening of the AWS Convention was the ceremony with a sign changing the name of historic Times Square to Welding Square by Theater and TV star Sally Kemp assisted by President-elect Al Chouinard. The sign remained up during the entire welding meeting week.

Missiles and Rockets Open Panel

An open panel on Missiles and Rockets Welded Fabrication was held at the Hotel Commodore on Wednesday under the chairmanship of D. B. Howard. The following experts were panelists: J. W. Jakubowski, D. W. Kinsey, R. D. Libert and J. F. Rudy. The panel excited a lively discussion from the audience.

Educational Lecture Series

An IIW representative from the Soviet Union, N. N. Rykalin, a professor at the USSR Academy of Sciences, received the Educational Lecturer Certificate Award for his well-attended lecture series "Heat

Educational lecture series given by N. N. Rykalin of the USSR draws large audiences during two sessions

Actress Sally Kemp and President-Elect Chouinard change Times Square to Welding Square

Sources, Heat Flow and Heat Effects in Welding," presented on Monday and Tuesday.

Dr. Rykalin is Head of the Welding Laboratory at the Institute of Metallurgy of the USSR Academy of Science. He is chairman of the USSR National Welding Committee, and is a foreign member of the Serbian Academy of Sciences. Dr. Rykalin has developed the theory and methods for calculation of heat flows in welding, covering more than 100 scientific investigations.

Additional Activities

Numerous meetings were held during the week including one by the Rockets and Missiles Welded Fabrication Committee. Several district meetings were held and the Membership Classes Committee, Subcommittee No. 1 of the Resistance Welding Committee, the Membership Activities Committee, the Welding Research Council Aerospace Advisory Committee, the Resistance Welder Manufacturers' Association, the Manufacturers' Committee, the Section Officers' Meeting and the American Institute of Electrical Engineers Electric Welding Committee Meeting were among the events held during Annual Meeting week. A number of luncheons and breakfasts were held including an Authors' breakfast each morning to orient authors for the day's technical meetings.

Praise Due Sections

Three sections, New York, New Jersey and Long Island, contributed manpower and organization to insure the smooth functioning and success of the Meeting. The men whose committees were responsible for doing such a fine job are: J. E. Dato, chairman, and H. C. Phelps, secretary, arrangements; H. D. Landis, chairman, president's reception, hospitality, signs and technical; J. Mikulak, chairman, technical meeting sessions; M. J. Giraldi, chairman, banquet; H. C. Cook and J. W. Flannery, co-chairmen, ladies' entertainment; E. W. Moles, chairman, plant tours; and A. V. Scherer, chairman, publicity.

President's Address

By R. D. Thomas, Jr.

President, American Welding Society, 1960–61

The 1961 Annual Meeting of the AMERICAN WELDING SOCIETY will always be remembered for its international flavor. This year more Americans than ever before are becoming conscious of welding outside the borders of their fifty united states. As President of your SOCIETY, I should like to direct your attention for a few moments to the benefits of the technical cooperation which now exists between the leading countries of the world and the increasing value of this effort for the future.

I choose this topic, not alone because I consider it appropriate for a combined meeting with the International Institute of Welding, but because it is a subject close to my heart.

It has been my good fortune to have known and exchanged views with many outstanding leaders in welding from foreign lands. Many of these men will share their experiences with us during the coming week. I am confident that their contributions will expand our outlook, as I am equally confident that we shall offer to our guests from abroad experiences that they will find rewarding.

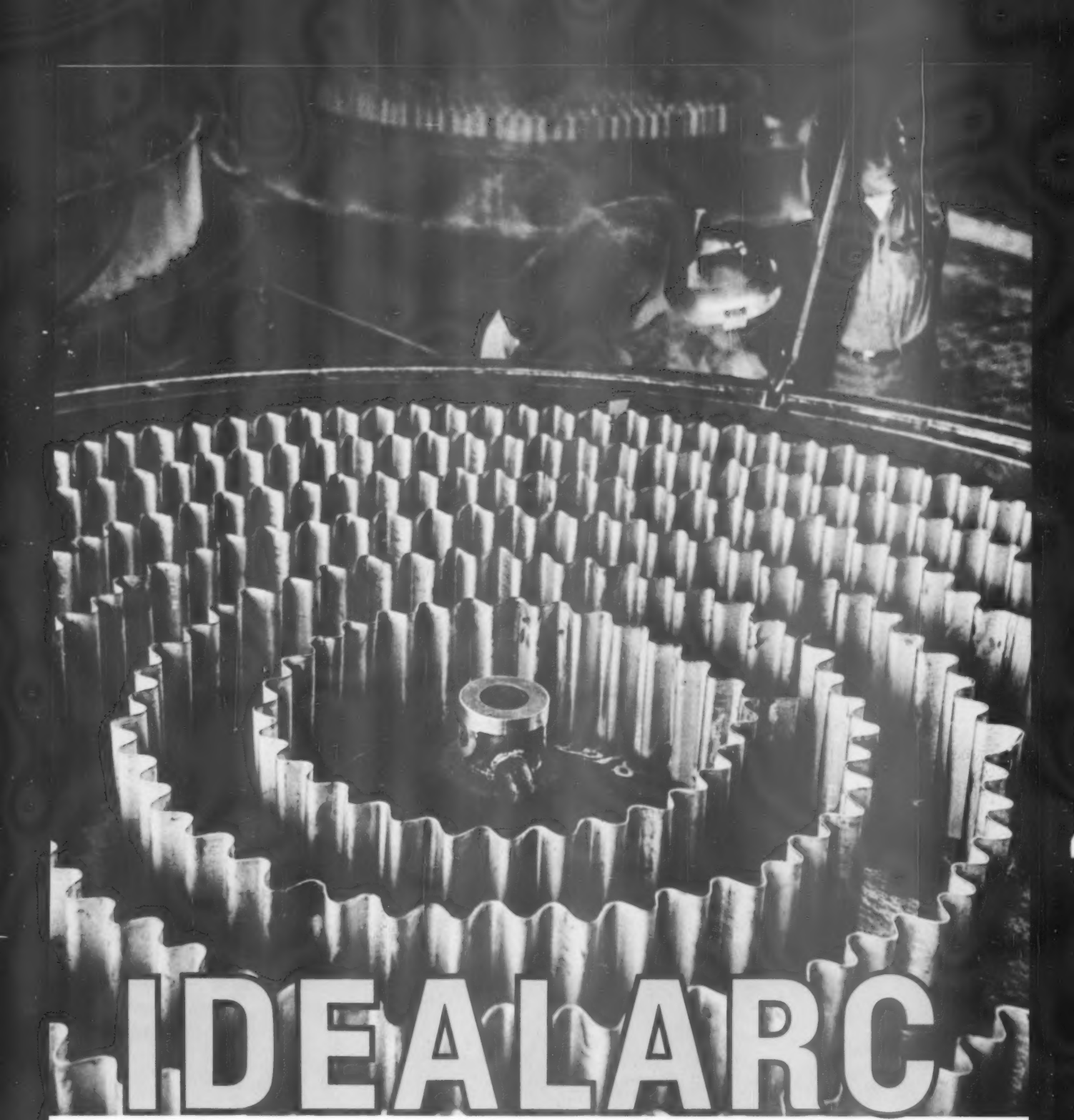
Belgian Ambassador Louis Scheyven, Annual Banquet main speaker

All of us engaged in one manner or another in the welding industry are fortunate in that we can clearly see the social significance of our occupation. We are builders. We take metal as it comes from our basic metal producers and we fashion bridges and buildings; ships, trains, airplanes and automobiles; machines, pressure vessels and pipelines; and hundreds of thousands of component parts. We are the smiths of a former age.

Much more than for the blacksmiths, coopersmiths, silversmiths or goldsmiths of the era prior to the industrial revolution, our occupation has become a scientific profession. The industry now embraces research scientists, engineers and technicians, as well as skilled artisans. The tremendous strides of the past forty years have made possible nuclear power plants, rockets and man-made satellites, chemi-

Manufacturer's Meeting at the Hotel Commodore was one of a number of meetings held during the Annual Meeting Week

For details, Circle No. 8 on Reader Information Card →



IDEALARC

Right at this moment, you may have a welding problem. The ideal solution is a welder which will most profitably perform the immediate task, and which will also permit you to change your operations to meet future market conditions or accommodate newly developed electrodes. On the next few pages, we propose to show that Lincoln Idealarc Welders are best suited to accomplish precisely these objectives.

These are Lincoln IDEALARCS on the job

Lincoln *Idealarc TM*, AC/DC machine is excellent for shipyard use. Most vertical and out-of-position welding takes DC electrodes, thus, the obvious need for DC current. Downhand welding, on the other hand, is usually done with iron-powder electrodes which take AC. Just a flip of the switch instantly changes current, lets the weldor select the correct current for each electrode, each job.

Here, straight AC *Idealarc TM's* predominate since this shop has been set up to operate on long production runs using AC electrodes. For this purpose, no other machine made will provide better service at lower initial or operating cost. Optional accessories let you tailor-make your TM for your particular operations.

In the Lincoln family of heavy-duty Idealarcs, there are three machines, the TM, the TIG and the R3M. R3M uses DC electrodes only; the TM, both AC and DC electrodes; and the TIG, any stick electrode or the inert gas process. One or more of these machines will handle every conceivable manual welding chore that could arise. And do it profitably!

Idealarc TM's are available in two different models, a straight AC and an AC/DC. When you select the AC/DC version, you can change from one current type to the other just by flipping a switch—it's that fast. Thus, you can take full advantage of those rods which work best on DC, or use the more recently developed electrodes which frequently require AC. Obviously, with the competitive demands for increased speeds and top electrode performance, the ability to select either AC or DC at a moment's notice gets more important each year. Because this is done so easily with the *Idealarc TM*, it is the favorite of many production men today.

Some work is, on the other hand, highly repetitive year-in, year-out. It may require either AC or DC. Here, low-cost, long-lasting equipment may be more important than machine flexibility. If yours is this kind of an operation, the *Idealarc TM* AC-model cannot be beaten for lowest cost, and the *Idealarc R3M* is the finest available three-phase DC-rectifier. It draws balanced current from the power line as do motor generator sets, but R3M's have the advantage of being essentially quiet. Further, when spatter control is important, such as on many stainless steel jobs, the R3M will give somewhat less spatter.

With the increased use of stainless steel, aluminum, magnesium and other special metals in modern fabrication, inert gas welding is becoming more important every day. To provide you with a welder which will perform TIG welding tasks and still be useful on normal stick welding jobs that make up the bulk of most shop work, Lincoln has developed the *Idealarc TIG*. With it, you can get both AC and DC welding current plus high-frequency, gas and water controls. In the TIG welder, then, you have the most complete, most versatile machine made.

Each Idealarc machine—as the name implies—is ideal for solving a variety of welding problems. To each you can add optional accessories such as remote current or polarity controls, even power packs to permit the largest sizes to be used as power sources for submerged arc welding. Thus you can select the model and optional accessories to suit immediate and foreseeable needs. You pay for no more. Why not let your Lincoln field engineer, a specialist in welding, explain the capabilities of each of these machines soon.

Shops like this one which consistently weld with and have need for a great many DC machines, may well wish to take advantage of the quiet operation of the *Idealarc R3M*, DC welder. Their highly efficient silicon rectifiers won't age or deteriorate. Special circuitry provides exceptionally good protection against overloads.

Here the *Idealarc TIG* is used as power source for inert gas process. Machine lets you weld with AC- or DC-electrodes, too. Factory-equipped with high-frequency, gas and water controls plus many other optional features. However, you select only those you need, and save the expense of buying unnecessary capabilities.

LINCOLN WELDERS

IDEALARC TIG's
AC or DC Inert Gas Plus AC or AC/DC

Idealarc TiG's are available in 300-amp models, both AC and AC/DC, with or without high-frequency, gas and water controls. All are NEMA rated machines. Ask Lincoln sales engineer for Bulletin 4608.1.

IDEALARC TM's
AC and AC/DC Welders

Idealarc TM's are furnished in 300, 400, 500 and 650-amp models in both straight AC and AC/DC models. Each is a NEMA rated machine. Want more information? Ask for Bulletin 4607.1 which describes 300-amp and larger sizes. 250-amp Idealarc described in Bulletin 4606.1.

IDEALARC R3M's
Three-Phase, Rectifier Welders

Idealarc R3M's are built in 300, 400, 500 and 650-amp sizes. Each is NEMA rated. Need details? Ask your Lincoln specialist for Bulletin 4609.1. Or write to:

THE LINCOLN ELECTRIC COMPANY

Department WW-9 Cleveland 17, Ohio

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT AND ELECTRODES

First IIW president P. Goldschmidt-Clermont, right, listens attentively to current president W. Edstrom

President's Reception with officers and guests getting acquainted in the spacious, but crowded, Windsor Ballroom at the Commodore

cal and petroleum processes, all of which could not have been achieved without modern welding techniques. In addition, we can all take credit for remarkable cost reductions in the construction industry and in many other applications where former joining methods had been used. Having evolved from an art to a science, welding has brought about improvements in the standard of living wherever it has been generally adopted.

The industry has been fortunate to have had the leadership of scientists and engineers who, because of their vision, have encouraged research and development even before the benefits could have been clearly foreseen. The results have justified their investment of time, effort and captial, so that today we find ourselves on a plateau above the mists which hid the peaks from our predecessors. We can see ever more clearly the value of additional efforts to reach the greater rewards. It remains for us, the welding leaders of today, to see that complacency does not set in and that we direct increased efforts in our field for the benefit of future generations.

When I speak of the leaders whose vision brought us to today's achievements, I include scientists from all over the world. Men like Portevin in France, Goldschmidt-Clermont in Belgium, Houdremont in Germany, to mention only a few of the famous names from nations across the waters. In the same class must be remembered men in this country like Elihu Thompson, Comfort Adams, Harry Boardman, William Spraragen and hundreds of others. We have been especially fortunate that our developments have transcended national boundaries, so that all have benefited from the contributions of our leading scientists in every nation.

We have had excellent media for written communications. The engineering and scientific publications of the world, and the patent libraries of each nation, have provided a means of exchanging new ideas, expanding our knowledge very much faster than if we were to have relied solely on the endeavors of each national group.

Written communcation alone, however, becomes a poor substitute for face-to-face conversation, once scientists have tasted the latter. The Annual Meetings of the International Institute of Welding, begun in 1948, have already paid handsome dividends to the countries who have participated.

For those of our members who have not become intimately involved in the operations of the International Institute of Welding, allow me to insert here a brief explanation of its functioning. The Institute's members are the technical societies, institutes and research groups from twenty-nine countries. Its work is conducted through fifteen commissions. Each country appoints one delegate on each commission and as many experts or observers as it chooses. These commissions meet annually, as they did during the past week, to examine the documents which have been submitted to it by national delegations and by subcommissions. Upon agreement within a commission and subsequently endorsed by the governing board, documents may be approved for publication. Actual publication rests for the most part with the national member societies.

The welding practices of all of the leading countries of the world may thus come under the scrutiny of this international body. Tests are frequently recommended, supplementing information collected by the various national groups. On the basis of the facts collected, recommended practices, codes, standards and classification systems are established. These can then be put to use by the national societies, or by other international groups, such as the International Standards Organization.

For many years the work of this

Those responsible for making the Annual Meeting and Welding Show a success attend the Arrangements Committee Luncheon

group was carried on largely by Western Europeans. This year, the Japanese form one of the largest delegations. In recent years several countries from Eastern Europe have made worthwhile contributions. Israel was made a member of the Institute at the meeting last week. No longer can it be said that any one country or group of countries dominates the deliberations of the Institute.

As faster means of transportation facilitates intercontinental travel, the number of participating countries increases. The steadily increasing attendance at each IIW Annual Meeting witnesses the greater significance that each nation places on the work of this organization. We in the United States have been gratified to see the increasing interest exhibited by the steady growth in the number of United States participants at each annual meeting since its founding thirteen years ago.

We appreciate the opportunity to serve as the hosts for the first time that the IIW had held its meeting outside Europe. The many participants from the far countries of the world have not been deterred by the thousands of miles of oceans that separate us. By bringing this meeting to the United States, American interest and participation in the work of the various IIW commissions have further increased. I am hopeful that the greater awareness of the IIW work by American scientists and engineers will spur an even greater degree of United States collaboration with consequent benefits to the United States, as well as to the other nations of the world.

The AMERICAN WELDING SOCIETY has for the past forty-one years provided United States industry with technical codes, standards and recommended practices which have guided the orderly development and use of welding processes. It is not surprising that our national tradition of self-sufficiency should have led many in our midst to question the need for participation in international welding commissions. For the most part, we have been inclined to stand aloof, proud of our accomplishments and unwilling to bear our share of the burden of responsibility for international codes and standards.

We Americans have behaved somewhat as our detractors have pictured us: unless outsiders speak our language (and the American idiom of English, at that), we cannot and shall not converse. The day for such isolationism is rapidly fading from the American scene. Our business, social and political leaders are urging the rising generation of Americans to increase their facility in foreign languages, to search out opportunities for discourse with visitors from abroad and to travel and study in foreign lands.

The benefit of international cooperation through frequent contact of scientists and engineers is already being felt by the European community. We in this country flatter ourselves that in some ways at least we may have provided the pattern which European engineers and businessmen have been following in recent years.

I refer specifically to the industrial machine developed in the United States by mass production. The most important single ingredient in our mass-production industry is reliable, sensible codes and standards. The automobile industry pointed the way toward the use of standard parts produced automatically in huge volumes at low cost. As the American worker increased his wealth-producing output, he found that he had the means to buy what he made and thus became an ever-growing consumer of his own output.

The second most important ingredient for the mass-production industry was a broad market. The United States of the early twentieth century was a huge country with a rapidly growing population and with valuable natural resources. The market was there within our own national boundaries. We had only to produce at low cost to generate the chain reaction which resulted in the sudden blossoming within a half-century of low-cost, mass-produced goods.

From across the waters, we view the European experiment in international trade cooperation as providing for participating countries the market essential to low-cost mass production. We view the increased collaboration of their scientists and engineers to generate codes and standards acceptable within all the nations as providing the second essential ingredient for low-cost mass production. The success of the venture can well point the way to additional common trade communities with consequent gains in material wealth and well being for the peoples involved.

Wherein, then, does our responsibility lie in providing a better world for the peoples of tomorrow? Our segment of the world industrial machine lies in the use of welding as a means for building future structures. International welding codes and standards for world-wide use should permit lower costs and greater benefits to a larger group of people. National codes which come under scrutiny of an international commission may well be modified as added experience and knowledge are brought to bear.

We hear all too frequently that our present codes are overly restrictive, and instead of allowing us the cost reductions provided by standard parts and standard methods, they increase costs by unnecessary quality standards or inspection routines. The complaint in many instances is sound and amendments are needed. Can the International Institute of Welding contribute to alleviating this condition?

By all means, yes. Unnecessary restrictions in codes or standards usually result from ignorance or lack of experience. How better to expand our knowledge and increase our experience than to gather together the leading scientists and engineers in the welding field to review each other's practices.

In opening this address, I pointed out that this joint meeting with the

Banquet scene in the Grand Ballroom of the Commodore Hotel where more than 600 persons attended

AWS members line up before bus whisks them to one of the many plant tours during Welding Week

International Institute of Welding could mark a new era of awareness by our membership of the importance of international communications on welding. To this end, I should like to conclude this address with a few observations on the influence that this meeting should have on the future activities of the AMERICAN WELDING SOCIETY.

Our Technical Department and Committees should begin at once to re-examine their current publications for conformity with international practices. Wherever the added knowledge or experience from foreign practices will permit simplification of our practices, these should be considered and adopted as soon as possible. We can no longer allow ourselves the luxury of sitting back comfortably and saying, "This has been satisfactory for these many years; why should we change?" Change we must, if simplification, lower cost or added benefits for the ultimate user are to result.

Our Information Center, along with its Publicity Committee, its Educational Activities Committee, and its Handbook Committee, has a similar responsibility to keep abreast of the efforts of foreign nations in promoting public understanding of welding and educating our youth and our engineers in welding.

Finally, our WELDING JOURNAL department and its committee must continue to watch the developments appearing in foreign publications and bring them to the attention of our members. This is our chief medium of written communication. In recent years it has increased its reporting of foreign contributions. With approximately 20% of the technical papers being presented by foreign authors at this meeting, the JOURNAL cannot help but show the influence of international welding developments during the coming year. Without the impetus of an international meeting in future years, a greater effort will be required to seek out and publish the important foreign developments.

American isolation, both political and technical, is at an end. From the plateau to which we have arrived by the efforts of hundreds of men from many of the countries of the world, we can see a myriad of peaks blazing in the sunlight. Our ability to scale those peaks becomes ever-so-much greater through the collaboration of others with similar objectives. As today's combined efforts speed our success, so shall tomorrow provide a better standard of living for all the peoples of the world.

Acceptance Address

By A. F. Chouinard

President-elect, American Welding Society, 1961–62

I want to thank you, President Thomas, for your kind and thoughtful introduction. And now I want to thank you, ladies and gentlemen, for your most generous expression of welcome to me, as I assume the Presidency of the AMERICAN WELDING SOCIETY during the coming year. I also want to thank each of you who has taken time to write me.

This is an honor that comes to few people in their lifetime, and I have a feeling of humility as I stand here. As you saw just a moment ago, I was escorted to this platform by two former presidents of this SOCIETY, Mr. MacGuffie and Mr. Plummer. Every one of you in this room knows them, and knows their reputation in our field; also each one of you knows how hard each one of them has worked for our SOCIETY.

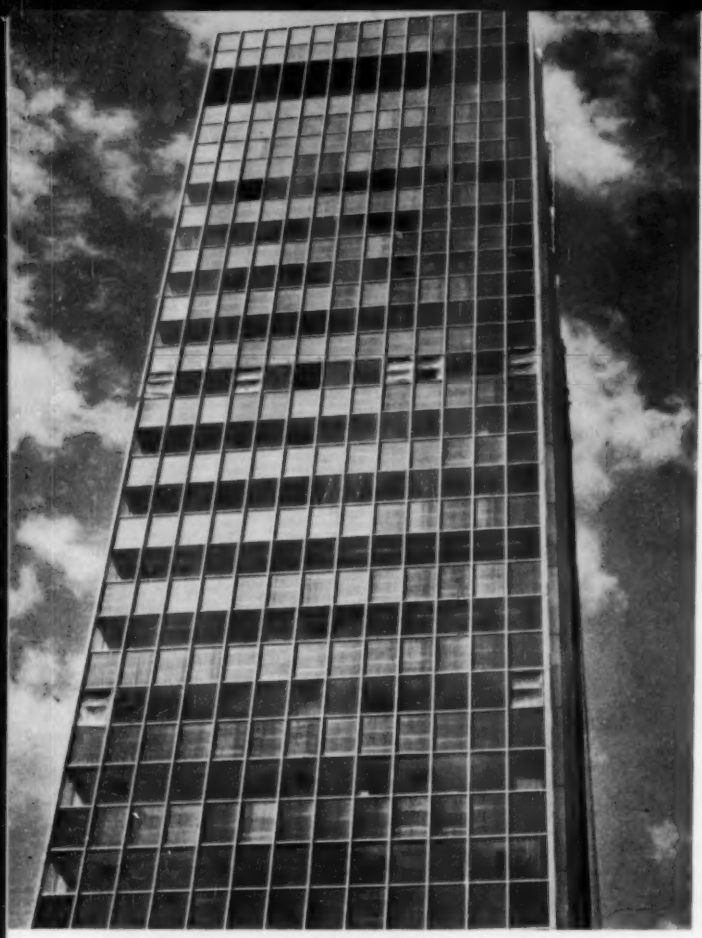
Now you can understand my feeling when I realize that I must perform to the standards that they and President Thomas have set in previous years. After having heard Dave Thomas' address this morning, you realize, I am sure, how high that standard has become.

I look forward to the coming year as one that will be a milestone in the SOCIETY's activities. This is to be the year that the AWS, together with all of the major engineering societies, will move into our new home, the new United Engineering Center. The elected officers who have participated in this decision know that the added facilities that will soon become available to us will permit the SOCIETY to provide added service to our members and to our welding industry.

This is a SOCIETY of service not only to its members, but also to the welding industry. Without this unselfishness, our SOCIETY would not today find itself in the vanguard of engineering skill of our country, and without our talents, many of the achievements of the past twenty years would not have been possible.

I feel strongly about the engineering skill that our members provide, but it must be increased in the years ahead. I will have more to say about this later on.

One of the many events for the ladies was a fashion show and breakfast at B. Altman & Co.



Soft clouds surround the UEC Building towering on the New York skyline near the East River

UNITED ENGINEERING CENTER

Skyline Scene

During the month of June contractors will install partitions on the 8th floor of the United Engineering Center in the final phase of constructing the new AWS headquarters. AWS offices overlook the active United Nations Plaza which is often in the international spotlight.

Several new sections appear on the Honor Roll for having achieved 100% or better of their goal. However, AMERICAN WELDING SOCIETY pledges stand at 73% of goal.

Honor Sections

Section	Goal, %	Section	Goal, %
Oklahoma City	125	Long Island	100
Mahoning Valley	113	Louisville	100
Holston Valley	109	Madison-Beloit	100
Cincinnati	104	Maryland	100
Hartford	104	Michiana	100
Kansas City	102	Nashville	100
N. E. Tennessee	102	New Hampshire	100
Puget Sound	102	New Jersey	100
Tulsa	102	N. Central Ohio	100
Baton Rouge	101	North Texas	100
Colorado	101	Northern N. Y.	100
Detroit	101	Northwest	100
Niagara Frontier	101	Olean-Bradford	100
Providence	101	Pascagoula	100
Rochester	101	Philadelphia	100
San Diego	101	Richmond	100
St. Louis	101	Salt Lake City	100
Birmingham	100	San Antonio	100
Boston	100	Sangamon Valley	100
Bridgeport	100	Santa Clara Valley	100
Chattanooga	100	Syracuse	100
Dayton	100	Toledo	100
Eastern Illinois	100	Western Mass.	100
Iowa	100	Wichita	100
Long Beach	100	Worcester	100

Pledges Needed to Meet Goal

Section	Needed	Section	Needed
Mohawk Valley	100	New Orleans	390
Tri-Cities	100	York-Central Pa.	435
Albuquerque	150	Fox Valley	450
Anthony Wayne	150	Saginaw Valley	460
Shreveport	195	Lehigh Valley	475
Arizona	200	Portland	485
Nebraska	200	Indiana	485
Washington	200	Stark Central	495
New York	218	Columbus	790
Carolina	245	Northwest	822
Northwestern Pa.	280	Milwaukee	917
J. A. K.	295	San Francisco	1008
Mobile	300	Cleveland	1090
Peoria	340	Houston (and Sabine)	1540
Susquehanna Valley	350	Chicago	1590
Western Michigan	350	Pittsburgh	1825
Iowa-Illinois	370	Los Angeles	2825
South Florida	370		

KEEPING YOU POSTED

By Fred L. Plummer

● April 9th to 21st—Thirteen activity filled days, unique in the history of the AMERICAN WELDING SOCIETY. Following months of careful planning and eager anticipation, outstanding leaders of the welding industry from all parts of our world gathered in New York to participate in the coordinated events comprising the 14th Annual Assembly of the International Institute of Welding and the 42nd Annual Meeting of the AMERICAN WELDING SOCIETY which included an AIEE Electric Welding Conference and the Welding Exposition.

● Facts and figures, formal reports and pictures appear elsewhere in this and other issues of the WELDING JOURNAL. In these notes, written very early during the morning of April 22nd, your gratified, proud and somewhat weary Secretary will attempt to present in chronological order some comments about people and events which may not be included in the more formal reports.

● On Sunday, April 9th, Mrs. Plummer and your Secretary moved from their home in Stamford to the Sheraton-Atlantic Hotel, headquarters for the IIW Assembly. That evening some 120 representatives of Belgium, Denmark, France, Germany, Italy, the Netherlands, Sweden, Switzerland, United Kingdom and Yugoslavia arrived at Idlewild Airport on an Air France chartered jet plane. They were greeted at the airport, photographed, assisted through health, immigration and custom formalities and transported by bus direct to the hotel where they had been preregistered and found room keys and Assembly enrollment documents ready for them. Founder President Goldschmidt, Past President Guerrera, Technical Secretary Leroy, Assistant Secretary Boyd, David J. Boag and Edwin Seymour-Semper were photographed in the press room at the airport.

● Monday evening, following an all day meeting of the IIW Executive Council, Mrs. Plummer and your Secretary were hosts at a reception and dinner attended by AWS President and Mrs. Thomas, IIW President Edstrom and his associate Axel Hanson, IIW Past Presidents Goldschmidt, Jaeger (with Mrs. Jaeger), Biers (with Mrs. Biers) and Guerrera, IIW Vice Presidents Vedeler and Kihara and IIW Secretaries Parsloe and Leroy with their associates Mr. Boyd, Miss Mercer, Mlle. Blosset and Mlle. Defond. Assembly Memorial Medals were presented to all members of the Executive Council.

● Tuesday evening President Edstrom and your Secretary spoke informally at a reception for members of the IIW Governing Council which had met during the afternoon. Admiral Thiele, representing the Ship Structure Committee and WRC Director Koopman joined your Secretary as representatives of the USA at this meeting. The Executive Committee of the American Council of the IIW met during the morning and the entire American Council during the evening to discuss final plans for the IIW Commission Meetings.

● At the opening session of the IIW Assembly on Wednesday morning, speeches by IIW President Edstrom, AWS President Thomas and A. B. Kinzel, representing the National Academy of Sciences-National Research Council, were reproduced on a screen in the complimentary language as each speaker presented his talk in English or French. During the evening the U. S. members of each of the 15 IIW Technical Commissions were hosts at receptions and in some cases dinners planned to afford all members of each commission an opportunity to meet informally. President and Mrs. Thomas were hosts at the reception for Commission XII. Mrs. Plummer and your Secretary were greeted during brief visits at the receptions of Commission XII by President and Mrs. Thomas, of Commission I by Mr. Barr and Mr. Magrath representing Mr. Levinstein, of Commission V by Mr. Sarchet representing Mr. Pulk, of Commissions IX-X by Mr. and Mrs. Larson, Mr. Felbeck and Mr. Vanderbeck, and of Commission II by Past President and Mrs. Chyle, before joining Arthur Gatewood for the reception and dinner of Commission XI at the Engineers Club.

● During Thursday President Thomas and your Secretary met briefly with each Commission, presenting Assembly Memorial Medals to the President of each of these 15 working groups with delegates, experts and observers representing 24 of the 29 member nations of the IIW. Heavy rains hampered but did not prevent the all day bus tour of New York with luncheon at Patricia Murphy's restaurant. That evening the French, Belgian, Swiss and Swedish Consulates held receptions to welcome guests from their countries. President and Mrs. Thomas visited three of these receptions with Mrs. Plummer and your Secretary, greeting M. Leroy, Mlle. Blosset, the Granjons, AWS President-elect and Mrs. Chouinard and others at the French Consulate, Mr. Goldschmidt, M. Lambrecht, M. Soete, M. Cito and daughter, the Herpols and others at the Belgium Consulate, and President Edstrom, Mr. Hanson, the Bylins and others at the Swedish Consulate. Mrs. Plummer and your Secretary also found it possible to greet Dr. and Mrs. Keel, Dr. Zeyen, M. Blanc and others at the Swiss Consulate.

● Past WRC Director W. Spraragen and Mrs. Spraragen were guests of honor at the IIW Reception on Friday evening at which IIW Past President H. Biers presented Assembly Memorial Medals to some of those responsible for the Assembly. These included in addition to AWS President R. D. Thomas, Jr., and Mr. Spraragen, the following: AWS President-elect A. F. Chouinard, AWS Past-President J. H. Humberstone (Chairman of the Underwriters Committee), Rear Admiral E. H. Thiele (Chief Engr. U. S. Coast Guard and Chairman Ship Structure Committee), WRC Director K. H. Koopman and Chairman Canadian Council of IIW R. A. Dunn.

● Four continental breakfasts in the Gate of Cleve restaurant and two buffet luncheons in the Ballroom provided additional opportunities for friendly greetings and the forming of new friendships. During Saturday evening IIW President Edstrom was host at a delightful and gay dinner with his companion Axel Hanson, the Biers, the Jaegers, the Plummers and the Thomases as

guests.

● Stormy weather resulted in the postponement of the Sunday boat excursion to Monday afternoon. Chairman Ed Dato presided at the Sunday luncheon meeting of the Arrangements Committee members and their wives. These representatives of the Long Island, New Jersey and New York AWS Sections together with members of the AWS Headquarters Staff were the persons responsible for planning and conducting all of the many activities, most of which are not even referred to in these notes.

● It is difficult to give any adequate conception of the hearty greetings, the good fellowship, the free exchange of ideas and information, the inspiration given and received, the new friendships formed, the suspicions dispelled and confidence established, the many intangibles which must inevitably result in better understanding and fuller cooperation of all who participated in these events.

● Space available permits only a word of appreciation to a few of the many who contributed so much to the success of the meetings:

● To AWS President Thomas who presented addresses at both IIW and AWS opening sessions, who presided at the banquet, many receptions, the opening of the Exposition, meetings of the Board of Directors and other groups, who headed the USA group of Commission XII, who presented medals, honors and awards, who attended many social events including the special Hawaiian Luau party for AWS officers and attendees of the 1960 Mid Pacific Conference—all in his usual quiet, effective, yet always impressive and frequently inspired manner.

● To Mrs. Thomas and Mrs. Plummer who on so many occasions served as friendly and gracious hostesses, who under the names of 'Ginney and Janey" acted as special correspondents for the "News," who helped their respective husbands with devotion and consideration far beyond the call of normal duty.

● To IIW President Edstrom who presided at all official IIW meetings and spoke at many AWS functions, always kindly, sincerely, and thoughtfully with messages of importance.

● To Dr. A. B. Kinzel who spoke at the IIW Opening Session forcefully, in fluent French.

● To AWS Past President J. H. Humberstone and the Underwriter Companies who supported these activities so generously.

● To AWS President-elect Chouinard who presented his acceptance speech (with his father a proud listener) at the AWS opening session, who attended meetings of two IIW Commissions, who has served as Chairman of our Technical Council, and who with Mrs. Chouinard attended many social events and other activities.

● To IIW Secretaries Parsloe and Leroy, and their staff associates Blosset, Boyd, Defond and Mercer, who organize all IIW activities and make possible the work of the 15 Technical Commissions.

● To IIW Past Presidents Goldschmidt, Jaeger, Biers and Guerrera who by their presence and counsel added dignity, prestige and wisdom.

● To IIW Vice President Vedeler and the Nordbys of Norway—host country for the 1962 IIW Assembly.

● To IIW Vice President Kihara and Dr. H. Suzuki who headed the large delegation from Japan.

● To Henri Granjon of France who presented the annual Adams Lecture.

● To N. N. Rykalin and B. E. Paton of USSR for their most important technical lectures.

● To the other foreign representatives of IIW who prepared and presented technical papers during the AWS meeting: Keel and Blanc of Switzerland; Colbus, Komers and Wolff of Germany; Bylin of Sweden, Cazaud and deLeiris of France; Van Douwen of The Netherlands; Carlson and Wells of United Kingdom; Christensen of Norway; Homes and Danhier of Belgium.

● To President Vilhalm of the Argentine Institute of Welding who presented membership pins to President Thomas and your Secretary.

● To the Presidents and Acting Presidents of the 15 IIW Commissions; Keel, Jaeger, Taylor, Blosset, Homès, Herpol, Leroy, Mrs. Granjon, Rühl, Weck, Sluis, Komers, deLeiris, Granjon and Guerrera.

● To our friends in the IIW Canadian Council—the Dunns, the Fosters, the Gooderhams, the Schneiders and others (Mrs. Guay and Miss Dobbin at the Canadian desk) who were responsible for the tour of the Niagara Falls area.

Welcome

• Supporting Companies

Effective Feb. 1, 1961:

Hyster Co.,
Danville, Ill.

Effective April 1, 1961:

Steelcase, Inc.
Grand Rapids, Mich.

Effective May 1, 1961:

Rawls Brothers Contractors, Inc.
Jacksonville, Fla.

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	F. G. Singleton	John Mikulak	A. N. Kugler
	C. B. Smith	E. F. Nippes	T. E. Jones
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AWS PAST-PRESIDENT DIRECTORS

R. D. Thomas, Jr. C. I. MacGuffie

- To AWS Vice Presidents Blankenbuehler and Jackson who have served as Chairmen of our Districts and Publications-Promotions Councils and made significant contributions to the meetings.
- To AWS Vice President and Awards Committee Chairman Jay Bland.
- To AWS Treasurer H. E. Rockefeller, new Honorary Member.
- To Exposition Manager R. T. Kenworthy who held a reception for IIW and AWS officers and others at the Sherry-Netherland Hotel.
- To Convention Chairman Ed Dato; Section Chairmen Bellware, Crowley and Thornton; and the many committee chairmen and members who worked with them.
- To Prof. R. T. Weil, Jr., who officially represented AIEE and Chairman R. P. C. Rasmusen of the AIEE Electric Welding Committee.
- To WRC Director Ken Koopman, Ship Structure Representatives E. H. Thiele and D. K. Felbeck.
- To Exposition Committee Chairman J. E. Norcross and Manufacturers' Committee Chairman T. S. Long.
- And finally and especially to members of the AWS Headquarters Staff: Asst. Sec. F. J. Mooney, Technical Sec. E. A. Fenton, Asst. to Sec. E. Krisman, Education and Information Sec. A. L. Phillips, Journal Editor T. P. Schoonmaker and their 32 associates and assistants.

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EDUCATIONAL ACTIVITIES

Annual Meeting at New York

The Annual AWS Meeting at New York in April was one of the most successful meetings the AMERICAN WELDING SOCIETY has every presented. Everything went very smoothly and all technical meetings were well attended. Those who did not attend the meeting this year will see by the pictures and comments in the WELDING JOURNAL that the Ballroom, in which the President's Reception was held, was filled to capacity. The banquet itself was well attended and was given an international flavor by our visitors from overseas. The ladies commented very favorably upon the orders and medals worn by our foreign guests and were particularly impressed by the rows of miniature medals worn by the Belgian ambassador, who was a guest of honor at the banquet. In response to many requests, 8 × 10 pictures of the banquet are available at $1 each. Contact the Information Center at national headquarters.

Educational Lecture

The Educational Lecture Series was one of the best attended since this activity was started. Professor Rykalin, of USSR, presented a masterly paper on the subject "Heat Sources, Heat Flow and Heat Effects in Welding." Those who attended were highly impressed at the scope of the paper. Many of those attending suggested that they would have to study the written paper very carefully to get the most out of it. The oral presentation, excellent though it was, would have to be supplemented by the written material if maximum benefit is to be obtained.

The EAC is giving consideration to having the entire lecture printed and made available for distribution since it is regarded as a distinct contribution to this field of welding literature. We predict this lecture will be long remembered.

International Institute of Welding

The International Institute of Welding, whose Annual Assembly was held the week prior to the AWS meeting, was voted a complete success and the SOCIETY is to be congratulated upon the presentation and upon its organization of the meetings and other activities.

Welding Show

The clocked attendance of the Welding Show exceeded 19,125. This is the greatest attendance we have had in our entire history and exhibitors reported upon the excellent quality of attendees. In nearly every case, it was reported that those contacted were in a position to buy or to specify and were deeply interested in what they saw. Many of those attending admitted that this was the first Welding Show they had seen. Only a minority are able to travel great distances each year to visit the Welding Show, and thus a different audience sees the Show every year.

Motion Picture

The first motion picture made of the Welding Show was taken at the Coliseum, New York City. It was decided that a picture of the chain cutting ceremony, followed by a visit to some of the exhibits, should be made. The chain cutting ceremony was performed by Mlle. L. Blosset of the French Institute of Welding, assisted by President-elect Al Chouinard. Mlle. Blosset operated like an expert and cut the chain with the skill of a seasoned welder. Al Chouinard stood by to help her, but his services were not needed. As they both moved from booth to booth, the movie camera followed them and took pictures of them inspecting the various exhibits.

If this movie turns out as we hope it will, it will be taken around the various sections to give all of you who did not have an opportunity to visit New York a view of the Welding Show.

Treasurama

The Treasurama attracted a lot of attention this year. The prizes were a portable TV set, a transistor radio and an electric razor. The staff in the AWS booth were kept continuously busy handing out questionnaires and all seats in the booth were occupied while attendees filled in the questionnaires and deposited them in the box. At 2:30 on the Thursday afternoon, IIW-President W. Edstrom drew the winning tickets from the box. The TV set was won by Raynor M. Thatcher, the radio by A. R. Mellini and the electric razor by Paul Edmiston. Telegrams were sent to the winners, congratulating them upon their success.

The objective of this contest was to find answers to questions which had been puzzling exhibitors for a long time. The tabulation from the thousands of questionnaires filled in should give us these answers and prove of great benefit to exhibitors.

Publicity

Each year the Publicity Committee prepares its program to suit the conditions governing the Welding Show. Each show is different, and each show is held in a different area. This year the publicity was geared to New York, where a very large population is concentrated within a comparatively small area. A window display was arranged in 42d Street, immediately opposite Grand Central Station, where an estimated three million people pass each week. There were pictures of welded buildings, bridges, United Engineering Center and a large illuminated transparency of an aerial view of New York City, the implication being that New York was built on welding. Also in the window was a large poster with a dramatic illustration of a cutting operation and drawing attention to the Welding Show at the Coliseum. Thousands of these posters were exhibited on notice boards of plants; 300 buses in the New York area carried posters, and National Welded Products Month was publicized not only in the New York area but all over the country.

National Welded Products Month

Congratulations are due to the many Sections which worked so hard to obtain proclamations and publicity for National Welded Products Month. At the Manufacturers' Meeting in New York—which was well attended—display boards were on view which showed the proclamations, photographs and news clips. It was a very impressive display and gave this important committee a first hand opportunity to see the tremendous amount of publicity obtained and the excellent work done by many of our AWS Sections.

1961 AWS NATIONAL FALL MEETING

SEPTEMBER 25–28, HOTEL ADOLPHUS, DALLAS, TEX.

REGISTRATION

HOTEL ADOLPHUS

Sunday, Sept. 24 • 3:00 P.M. to 6:00 P.M.
Monday, Sept. 25 • 8:00 A.M. to 4:00 P.M.
Tuesday, Sept. 26 • 8:00 A.M. to 4:00 P.M.
Wednesday, Sept. 27 • 8:30 A.M. to 3:00 P.M.
Thursday, Sept. 28 • 8:30 A.M. to 3:00 P.M.

SEPTEMBER 25, MONDAY MORNING

10:00 A.M.—Official Opening Session

WELCOME ADDRESS

A. F. Chouinard, President, AWS

KEYNOTE ADDRESS

(Speaker to be announced later)

SEPTEMBER 25, MONDAY AFTERNOON THREE SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

1. Ultra High-strength Steels

A. Causes of Microcracking and Microporosity in Ultra High-strength Weld Metal
by Milton D. Randall, R. E. Monroe and P. J. Rieppel, Battele Memorial Institute

B. Weldability Study of Hot-work Tool Steels
by N. A. Sinclair, J. G. Maciora and R. P. Sopher, Electric Boat Division, General Dynamics Corp.

C. High Weld-joint Efficiencies in a Work-hardening Stainless Steel
by William P. Hatch and W. C. Malatesta, Watertown Arsenal Laboratories, and George M. Orner, Manufacturing Laboratories, Inc.

2. Nuclear Components

(Sponsored by AEC Welding Forum)

A. Variable Weld Penetration and Its Causes
by J. J. Chyle, A. O. Smith Corp.

B. Effect of Welding Power Supply on Weld Quality
by C. C. Stone, Argonne National Laboratory

C. Control of Fissuring in Inconel by Regulating Process Variables
by J. D. Carey, General Electric Co.

3. Research and Weldability

A. New Developments in Gas Shielding
by Eugene F. Gorman, Linde Co.

B. Welding Nodular Cast Iron Without Post-weld Annealing
by Robert C. Bates and Fred J. Morley, Jr., Westinghouse Electric Corp.

C. Temperature Distribution During Welding of Connections in Concrete Structures
by A. A. Toprac and J. Neils Thompson, University of Texas

SEPTEMBER 26, TUESDAY MORNING

THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

4. Aircraft and Missiles

A. Fabricating High Temperature Components for Reaction Motors XLR-99 Rocket Engine
by Guido A. Andreano, Thiokol Chemical Corp.

B. Bi-axial Strength of Welds in Heat-treated Sheet Steel
by Clyde M. Adams, Jr., MIT, and Donald A. Corrigan, Watertown Arsenal Labs.

C. Sheet Fracture Toughness Evaluated by Charpy Impact and Slow Bend
by George M. Orner and Carl E. Hartbower, Manufacturing Laboratories, Inc.

5. Nuclear Plant and Cryogenic Materials

A. Investigation of Induction Welding for Remote Maintenance
by Arthur L. Lowe, Jr., G. R. Winders, and M. Christensen, Babcock & Wilcox Co.

B. The Welding of Beryllium
by R. G. Gilliland and G. M. Slaughter, Oak Ridge National Laboratory

C. Impact Properties of Stainless Steel Weld Joints at Cryogenic Temperatures
by H. W. Mishler, Battelle Memorial Institute, and H. J. Nichols, United States Steel Corp.

6. High-strength Low Alloy Steels

A. Improvement of Low-cycle Fatigue Strength of High-strength Steel Weldments
by M. D. Randall and R. E. Monroe, Battelle Memorial Institute, and H. Fall and D. Brugioni, Caterpillar Tractor Co.

B. Development of Procedures for Welding High-yield Steel
by Clarence E. Jackson, Linde Co., and Larry Robbins, Mare Island Naval Shipyard

C. Study of the Causes of Cracking the Submerged Arc Welds in Low-alloy Constructional Steels
by M. D. Randall, R. E. Monroe, Battelle Memorial Institute, and H. J. Nichols. United States Steel Corp.

SEPTEMBER 26, TUESDAY AFTERNOON

TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

7. Aircraft and Missiles

A. High Quality Aluminum Gas-metal-arc-spot Welding for Launch Space Vehicle Applications
by Daniel M. Daley, Jr., W. M. Campbell and J. C. McCaig, Redstone Arsenal

B. Superalloy Multilayer Sandwich Structures for Application to 1800° F
by Harold Smallen, Norair Division, Northrop Corp.

C. Welding Evaluation of High Temperature Alloy Sheet Materials by Restrained Patch Testing
by Stanley Weiss and Warren P. Hughes, General Electric Co.

8. Shop Practice

A. Welding Keeps Oil Refinery Mechanical Equipment Operating
by Ray M. Kolb, American Oil Co.

B. Hose for Oxygen Cutting Processes
by Paul Hoffman, Electric Hose and Rubber Co., and E. Meincke, Linde Co., for the Hose Technical Committee of the Rubber Manufacturer's Association

C. How Specifications Influence Gas Pressure Regulator Design
by Byron H Acomb, Linde Co.

SEPTEMBER 27, WEDNESDAY MORNING THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

9. Electron Beam Welding

A. Characteristics and Strength Data of Electron Beam Welds in Four Representative Materials
by Robert E. Roth and Nick F. Bratkovich, Allison Division, General Motors Corp.

B and C. Electron Beam Welding of Refractory Alloys
by Sheldon S. White, Harvey J. Lander, Wendell T. Hess, Alloyd Electronic Corp.

10. Nondestructive Testing

(Sponsored by SNT)

A. Nondestructive Testing in Utilities, Commercial, Nuclear Steam Generating Equipment
by William Bunn and E. S. Proctor, Combustion Engineering, Inc.

B. Maintenance Inspection of Welds and Materials in Service
by Dwight J. Evans, Engineering Test Service, Inc.

C. Preparation of Materials—Interpass and Final Inspection of Welding in the Fabrication of Pressure Vessels and Submarine Hulls
by Thomas J. Dawson, Ingalls Shipbuilding Corp.

11A. Basic Research

A. Residual Stresses in Welded Plates—A Theoretical Study
by Lambert Tall, Fritz Engineering Laboratory, Lehigh University

B. The Effect of Plate Thickness and Radiation on Heat Flow in Welding and Cutting
by Clyde M. Adams, Jr., and Pravin Jhaveri, MIT

SEPTEMBER 27, WEDNESDAY AFTERNOON TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

11B. Basic Research

Seminar following discussion of papers presented in Session 11A.

12. Applications

A. Magnetic-flux Gas-shielded Arc Welding on Boiler Fabrication
by Frank W. Armstrong, The Babcock & Wilcox Co.

B. Plasma Arc Welding Surfacing
by Robert S. Zuchowski, Linde Co., and Russell Culbertson, Haynes Stellite Co.

C. Gas Metal-arc Welding Aluminum with Large Diameter Fillers
by James A. Liptak, Kaiser Aluminum & Chemical Corp.

SEPTEMBER 28, THURSDAY MORNING

TWO SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

13. Special Processes

A. Properties of Friction Welding Plain Carbon and Low Alloy Steels
by Thomas H. Hazlett, University of California

B. Electromagnetic Stirring of Arc Welds
by David C. Brown, Frank A. Crossley, John F. Rudy and Harry Schwartzbart, Armour Research Foundation of Illinois Institute of Technology

14. Pressure Vessels and Heat Exchangers

A. Corrugated Monel Heat Exchangers
by J. F. O'Connell, N. J. Ritchey and J. C. Stewart, A.M.F. Beaird Co.

B. Properties and Fabrication of High Strength $2^1/_4\%$ Chromium–1% Molybdenum Materials
by Robert C. Griffin and George N Emmanuel, The Babcock & Wilcox Co.

C. Accelerated Cooling of Carbon Steels for Pressure Vessels
by Robert D. Stout, Domenic A. Canonico and Edward H. Kottcamp, Lehigh University

SEPTEMBER 28, THURSDAY AFTERNOON

TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

15. Titanium and Beryllium

A. The Welding of Titanium to Steel
by D. R. Mitchell, Titanium Metals Corp.

B. Welding of 2-in.-thick Titanium-alloy Plate
by R. L. Koppenhofer, W. J. Lewis and G. E. Faulkner, Battelle Memorial Institute

C. Diffusion-bonding High-temperature-alloys with Beryllium
by William Feduska and Walter L. Horigan, Westinghouse Electric Corp.

16. Piping

A. Automatic "Stove Pipe" Welding Comes to the Pipe Lines
by Howard B. Cary, Hobart Brothers Co., W. B. Handwerk, Crose-Perrault Equipment Corp., and B. K. Elliott, H. C. Price Co.

B. An Automatic CO_2-shielded Welding Process for Double-joining Pipe
by J. W. Nelson, Glenn E. Faulkner, P. J. Rieppel, Battelle Memorial Institute

C. Automatic Welding of Transmission Line Pipe
by Roger W. Tuthill, Air Reduction Sales Co.

This schedule of technical papers is not necessarily final. A more complete and detailed program, including an account of other activities, will be published in the September issue of the WELDING JOURNAL.

SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

Alabama

LECTURE SERIES

Birmingham—The *Birmingham* Section recently completed its second annual Welding Lecture Series, and it definitely was a successful program. More than 80 persons registered and many attended without registering so that attendance was very good at all of the lectures.

On Tuesday, March 21st, Dr. R. W. Sandelin, chief metallurgist, Connors Steel Division, presented the first lecture on Welding Metallurgy. This lecture dealt with the basic principles affecting weld properties, primarily ferrous metals.

The second lecture on "Automatic and Semiautomatic Welding" was given on March 28th by Clarence E. Jackson, associate manager of electric welding development, Linde Co., Newark, N. J. As the subject indicates, Mr. Jackson discussed "Mechanized and Semi-Mechanized Welding of Carbon Steels." On April 4th, W. R. McMahon, chief welding engineer, The Ingalls Iron Works Co., lectured on "Welding Cost Control." A discussion of various factors affecting welding costs and a guide to selection of the most economical process to use were included in this talk.

The fourth lecture, which coincided with the monthly meeting, was held on April 11th and featured J. F. Kiernan, section leader, Air Reduction Sales Co., talking on "The Oxygen Cutting Processes." This talk covered the general aspects of oxygen cutting with particular reference to the three major elements involved—the cutting oxygen stream, the cutting speed and the preheat flames.

This lecture series was under the general direction of the Technical and Education Committee with J. R. McFarland as chairman.

ELECTION OF OFFICERS

Birmingham—The *Birmingham* Section announces the election of the following officers for the 1961–62 season: Chairman, C. T. Estock; Vice-chairman, C. H. Faulkner, Jr.; Secretary, K. V. Nickell.

INTRODUCES GUEST

Los Angeles Section Chairman, John Wiley, as he introduced Dominick Sanchini, guest speaker for the March 16th meeting

California

ROCKET ENGINES

Los Angeles—The *Los Angeles* Section had as guest speaker for the March 16th technical meeting, Dominick J. Sanchini, assistant program engineer of the NASA sponsored program for the 1,500,000 lb thrust liquid-propellant rocket engine. The title of his talk was "The Development of High-Thrust Engines for Large Vehicles."

The meeting was held at the Rodger Young Auditorium, with approximately 60 members and guests in attendance. Mr. Sanchini spoke on the design, development program and application of the 1,500,000 lb thrust Rocketdyne F-1 engine under development by Rocketdyne for NASA. He also discussed the F-1 test facilities and the development program status to date. The paper was well supported by slides. A film in color of 17 min duration showed the progress made in the missile engine field.

ARC WELDING PROGRESS

San Diego—The *San Diego* Section held their monthly meeting at the Midway Chuck Wagon Restaurant on March 15.

The speaker at the technical meeting was R. R. Kilgore, welding engineer with the Lincoln Electric Co., Los Angeles, who gave a very interesting talk on the "Progress of Arc Welding."

NEW PROCESSES

Sunnyvale—On March 28th, the *Santa Clara Valley* Section met at Sabella's "Ebbtide Room" for dinner and meeting.

The speaker of the evening, Harry Schwartzbart, welding research supervisor of Armour Research Foundation, Chicago, Ill.,

SANTA CLARA SCHOLARSHIP AWARDS

L. A. Mayr of Santa Clara Valley Section presents $100 scholarship awards to K. R. Carson and W. G. Morris of Stanford University; W. D. Donnelly of Stanford University looks on. Left to right are W. D. Donnelly, K. R. Carson, W. G. Morris and L. A. Mayr

reviewed the past history of welding and then discussed the latest techniques and processes being used in the welding field.

Mr. Schwartzbart's descriptive talk covering the newer welding methods was of great interest to the audience. The talk gave rise to many questions regarding present limitations for the use of the new techniques, the amount of actual production use being made of them, and what production and engineering people may expect to gain in the future from their use.

Among the topics discussed were ultrasonic, electroslag, high-frequency resistance, plasma jet, electron beam, friction welding and short-arc welding. He also discussed tests conducted at Armour Research with the use of lithium during silver brazing of stainless steel. Mr. Schwartzbart maintained a high degree of interest from his audience throughout the discussion.

Colorado

PLANT TOUR

Denver—The March meeting of the *Colorado* Section was held at Cavaleri's Restaurant on March 14th. The group gathered at about 6:30 P.M. for an appetizer until 7:00 P.M. when dinner was served.

The technical portion of the meeting was a plant tour of the Denver Division of The Sundstrand Corp., and was under the direction of Frank Tipner. Sundstrand Corp. are manufacturers of constant speed transmission, gear boxes, hydraulic motors and pumping systems related to the aircraft industry. Most of the plant operations are in the machine shop field; however, welding plays an important part in the over-all production setup.

Dave Card of C. S. Card Iron Works was the coffee speaker and reviewed the AWS Code of Ethics.

ELECTRIC POWER

Denver—The April meeting of the *Colorado* Section was held on April 11th at Cavaleri's Restaurant in Denver. Forty-five members gathered at 6:30 P.M. for an appetizer and at 7:00 for dinner.

The guest for this meeting was J. G. Daniels, district sales manager for the Chicago Bridge & Iron Co. He presented two sound films, "Power from Niagara" and "Dresden Sphere." Both projects had received world-wide recognition and proved very interesting to the audience.

Keith Warren of the National Bureau of Standards, Boulder, Colo., was the coffee speaker. His talk was on cryogenics.

District of Columbia

GAS-SHIELDED ARC WELDING

Washington—On February 16th, the *Washington* Section met at the Hotel Ebbitt for regular monthly dinner; and at the Auditorium of the Washington Gas Light Co. for regular monthly meeting. Technical speaker was Gilbert R. Rothschild, assistant director of Metallurgical Research at the Central Research Laboratories of the Air Reduction Co., Murray Hill, N. J. His subject was "A Survey of Gas-Shielded Arc-Welding Processes."

Mr. Rothschild covered all phases of shielded gas welding: the characteristics of the inert and active gases used, their advantages and disadvantages; the tungsten-arc and consumable - electrode processes, power supply requirements; and the uses and limitations of each process. Of particular interest were movies which clearly showed the different modes of metal transfer for the consumable-electrode processes.

Illinois

ELECTRIC WELDING MOVIES

Danville—Through the courtesy of the Linde Co., six films of electric processes were shown by John W. Carrier at the March 22nd meeting of the *Eastern Illinois* Section. Mr. Carrier also answered many questions raised by the films.

The films shown were: "Automatic Precision with Heliarc Spot Taped Programming"; "Heliarc Welding of Carbon Steel Pipe"; "Modern Methods of Joining Metals"; "Welding Advances with Aluminum"; "Unionarc Welding"; "High-Speed Sigma Shortarc."

NONDESTRUCTIVE TESTING

Aurora—The March meeting of the *J. A. K.* Section was held at the Fox Valley Country Club in Aurora on March 9th. The meeting was kicked off with a smorgasbord dinner, which was followed by a fine coffee speaker. The golf "pro" from the Fox Valley Country Club gave a fine exhibition of the do's and don'ts of golf.

Keith Van Kirk of the Magnaflux Corp. was the technical speaker. He gave a good talk on "Nondestructive Testing of Weldments" which was accompanied by an excellent movie.

ATOMIC SUBMARINES

Peoria—Nino Pompilio of the Electric Boat Div., General Dynamics Corp., was guest speaker at the March 15th meeting of the *Peoria* Section. Mr. Pompilio talked in general terms on the welding of atomic submarines. He also showed movies of trips taken by these submarines.

Indiana

PLANT TOUR

Fort Wayne—The February meeting of the *Anthony Wayne* Section was held at the Colonial Restaurant on February 23rd.

After dinner, Harry Johnson gave a brief history of Wayne Welding Supply Co. Thirty-five members and guests then toured Wayne's liquid gas plant.

GAS METAL-ARC PROCESSES

Cumberland—Sixty-five members attended the March 24th meeting of the *Indiana* Section held at Buckley's Restaurant in Cumberland. Following the dinner and a short business meeting, Paul Hall introduced W. G. Koepsell, assistant manager of sales engineering, Automatic Systems, Westing-Arc Div. of the Westinghouse Electric Corp. Mr. Koepsell spoke on "Automatic Gas Shielded Metal-Arc Welding Processes as Applied to Welding of Mild Steel."

For discussion, he subdivided these processes into (1) inert-gas shielded argon-arc reverse polarity, (2) inert-gas shielded argon-arc straight polarity, (3) CO_2 reverse polarity and (4) CO_2 straight polarity. Slides were used to describe the characteristics of each process, and available data covering relative costs, standard time, equipment and tooling costs for many specific applications were presented. Most applications were related to automotive component manufacture requiring high speed production and utilizing multiple torch setups. Application of the arc spot-welding processes for mild steel fabrication was also covered.

Iowa

PRODUCT DESIGN

Des Moines—John Mikulak, assistant to the vice president of

Manufacturing, at the Worthington Corp., Harrison, N. J., was guest speaker at the March 16th dinner meeting of the *Iowa* Section held at the Hotel Kirkwood.

First, Mr. Mikulak pointed out the need for a correct approach to his talk on "Product Design for Welding." He then illustrated the difference between designing for castings, riveting, and other methods of fabrication as compared with welding. He pointed to the economy of welding and its strength factor versus weight in the welded product.

Kansas

MICRO-WIRE WELDING

Wichita—The *Wichita* Section held their March meeting on the 13th at the University of Wichita, Shocker Room, in the Student Activities Center. Dinner of southern fried chicken was served by the student chefs to forty-three attendees.

The group enjoyed a very educational presentation of "Micro-Wire Welding," which was presented by Howard B. Cary, director of the Technical School, Hobart Brothers Co., Troy, Ohio. Mr. Cary outlined the background of automatic and described events leading up to the development of Micro-Wire Welding. The process was described along with customer applications.

ALUMINUM WELDING

Wichita—The *Wichita* Section held a special joint meeting with the American Society for Metals at the University of Wichita Student Activities Center on Monday, April 10th. Forty-two members of both societies attended the dinner prior to the meeting.

W. M. Rogerson of the Aluminum Co. of America made a comprehensive presentation of aluminum fusion welding and resistance welding to include weldable alloys, procedures and equipment performance. The talk dealt with various commercial applications including aircraft. Slides were used to illustrate the talk. Mr. Rogerson displayed a vast knowledge of his subject.

Massachusetts

WELDING RESEARCH

Watertown—One hundred and fifty-four members and friends of the *Boston* Section were guests of Watertown Arsenal on March 13th. After a social hour and dinner the group was warmly welcomed by Colonel R. B. Braid, commanding officer of Watertown Arsenal.

Donald C. Buffum, chief of the Metals Joining Branch of the Laboratory, reviewed present programs in progress at the Arsenal Laboratory.

The main speaker of the evening was G. D. Chandley, chief metallurgist of the Arsenal Operations Division. Mr. Chandley with the use of slides discussed problems encountered at the Arsenal in its position as peacetime job shop for the entire Ordnance Corps. He also outlined welding problems of the future as follows: Revised specifications on joint efficiency; quenching and tempering instead of stress relieving; wider use of qualified welders and procedures; and use of more air-hardening steels; increased use of uncommon metals; distortion free welding of machined weldments; greater use of magnaflux, dye penetrant, and other tests will be employed.

At the conclusion of the talks, the guests enjoyed a guided tour of the Arsenal's Welding Fabrication Shop and Research Laboratory.

DOUBLE HEADER

Boston—Coinciding with the start of the baseball season, the *Boston* Section staged a "double header" at the April 10th dinner meeting held at the Bostonian Hotel. After dinner one hundred and forty-two members and guests heard two informative talks keyed to automation and costs.

James P. Whelan, president of Whelan Engineering Corp., Quincy, Mass., spoke on "Fabricated vs. Cast Parts for Automated Packaging Equipment." A color film of automatic glass container clean units in action contrasted an earlier cast model with a new, streamlined, welded, fabricated unit. Mr. Whelan stressed the freedom of design made possible by the switch to welded construction. In spite of rising costs, a 25% savings was realized by the change.

Charles Schultz, New England representative for Reid-Avery Co., used slides in conjunction with this talk on "Automation of Welding for Automotive Production." His talk covered CO_2 and open-arc welding of tail pipes, mufflers, housings and other automotive equipment. De-

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DINNER IN WORCESTER

Members and guests of the Worcester Section enjoy dinner before listening to Dana Wilcox who was guest speaker at the March 13th meeting.

tailed descriptions of positioning equipment, welding heads and part designs for automatic welding were also provided.

UNDERSEA CRAFT

Springfield—Nino Pompilio of the Electric Boat Div., General Dynamics Corp., Groton, Conn., was the guest at the April 11th meeting of the *Western Massachusetts* Section held at the Oaks Inn, Springfield.

Mr. Pompilio showed two motion pictures, one of the Nautilus undersea trip under the ice at the North Pole, and the other of the Triton's undersea trip around the world. He also showed a movie on the welding of pipe.

ALUMINUM

Worcester—Dana Wilcox of Reynolds Aluminum was the guest speaker at the March 13th meeting of the *Worcester* Section.

Mr. Wilcox, with the aid of color slides, gave a most interesting presentation of the new uses of aluminum for structures and piping. His background with Reynolds, a world leader in the field of aluminum, is an excellent basis for pointing out how important aluminum is and how many things will be produced from aluminum in the future. Aluminum is of major influence in our lives today.

GIFT FOR A GUEST

Guest Speaker F. J. Pilia (right) is shown opening token gift from A. W. Brown at Detroit Section meeting on April 14th

Michigan

PROGRESS THROUGH WELDING

Detroit—"Progress Through Welding" was the topic discussed by Frank J. Pilia before the *Detroit* Section on Friday, April 14th, at the Engineering Society of Detroit. The subject matter was very timely for a meeting during National Welded Products Month.

The average car has better than $13 worth of welding were Mr. Pilia's opening remarks. These were followed by a thumbnail history of the development of welding—hammer welding, bare wire, coated electrodes in the 1930's, automatic and submerged-melt welding, and finally precision welding as developed in the last five years.

As special projects engineer for the Electric Welding Development Dept. of the Linde Co., Mr. Pilia has become acquainted with many manufacturing methods and welded products. His field has ranged from missiles to watches, from job shops to nuclear reactors, aircraft, automobiles, and refrigerators. In recent years he has devoted most of his time to development and applications for proper tooling to allow for mechanized welding.

Many fine slides and two films were used to supplement and illustrate his remarks. Shown were examples of precision welding used on nuclear, jet aircraft components, and many unusual applications from manual welding to fully automatic programed welding on tape controlled machines.

ELECTRONIC CONTROLS

Saginaw—Bud Mack of the Budd Co., Chicago, was the guest speaker at the April 6th meeting of the *Saginaw Valley* Section.

Mr. Mack gave a very good talk with slides on the principles and applications of the Budd Monautronic Welding Controls.

POWER SOURCES

Grand Rapids—"Power Sources for Gas-Shielded Arc Welding Processes" was the subject of an excellent, illustrated talk given at the March 27th meeting of the *Western Michigan* Section, by Everett Cushman, supervisor of Welding and Joining Research Engineering for Air Reduction Co., Murray Hill, N. J.

The talk covered the merits of drooping, rising and constant voltage power supplies for gas-shielded metal-arc welding and the effects on welding performance of M/G and rectifier machines. As resistance welding is very popular in this district, it commanded a sizable crowd of 40 which showed a great deal of interest. A lively discussion period followed.

Minnesota

SYNTHETIC GEMS

Minneapolis—On the regular meeting date of March 13th, the *Northwest* Section held a Ladies Night, which featured P. T. Kinney of the Linde Co., who discussed the manufacture of synthetic gems in a talk entitled "Linde's Crystal Magic." A door prize of a synthetic star sapphire was won by one of the lucky guests, Mrs. Schnagl.

This type of program proved to be very successful and will, no doubt, be repeated in future years.

New Mexico

WELD STRESSES

Albuquerque—The *Albuquerque*

Section held its monthly meeting on April 13th at the Desert Inn.

The guest speaker was H. R. Kretchmar, a welding engineer for the Phillips Petroleum Co., Bartlesville, Okla. His subject was "Welding Stresses Viewed with Polarized Light." With the aid of slides and the polarized light, he explained how the study of stress distribution in various types of weld joints helps the welding engineer. He described how the light reveals the shape of the joint and has a marked effect upon the distribution of stresses. By proper study it is possible to obtain uniform stress distribution.

New York

JOB SHOP WELDING

Bellmore—The *Long Island* Section held its regular monthly meeting on April 13th at the Sunrise Village Restaurant in Bellmore, L. I. Featured speaker was George Williams of Air Reduction Sales Co. Mr. Williams' talk on "Welding in the Job Shop" emphasized the delineation between the very exacting techniques and specifications as set forth by the large agency-sponsored projects and the somewhat less sophisticated but equally important activities in the small fabrication shop. A 16-mm sound film illustrated the talk.

LONG ISLAND GUEST

Speaker G. Williams is shown addressing members of the Long Island Section at April 13th meeting

ELECTRODE COATINGS

Pittsfield—"It Isn't Mud" was the approach taken by Harry F. Reid of the McKay Co. in presenting an interesting and informative discussion on the development of electrode coating materials at the April 6th meeting of the *Northern New York* Section held at the Stanley Club in Pittsfield, Mass.

During the talk, Mr. Reid emphasized that functional advantages of coatings are numerous and varied but could be separated into four general areas encompassing electrical, slagging, metallurgical and manufacturing. Coating materials were also divided into classifications, depending upon their effect on the welding characteristic of a type or class of electrode, and were discussed in more detail. It was shown that the selection of coating materials used in developing coating formulas depends primarily upon the end use of the electrode.

ELECTRON BEAM WELDING

Olean—The *Olean-Bradford* Section held its monthly meeting on March 21st at the Castle Restaurant in Olean, N. Y.

J. W. Kehoe, director of District 3, spoke of the good work the Section

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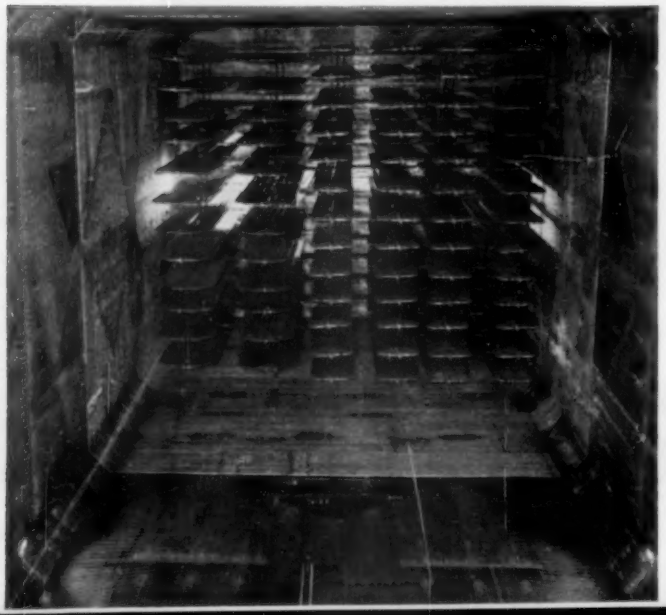
Situated on the banks of the Delaware River south of Philadelphia, Eddystone is the first power station in the world designed to produce steam at the supercritical pressure of 5,000 pounds per sq. in. and a temperature of 1200° F. This breakthrough in the commercial generation of electricity is expected to set a new world's record for power station efficiency by producing a kilowatt hour from 2/3 pound of coal.

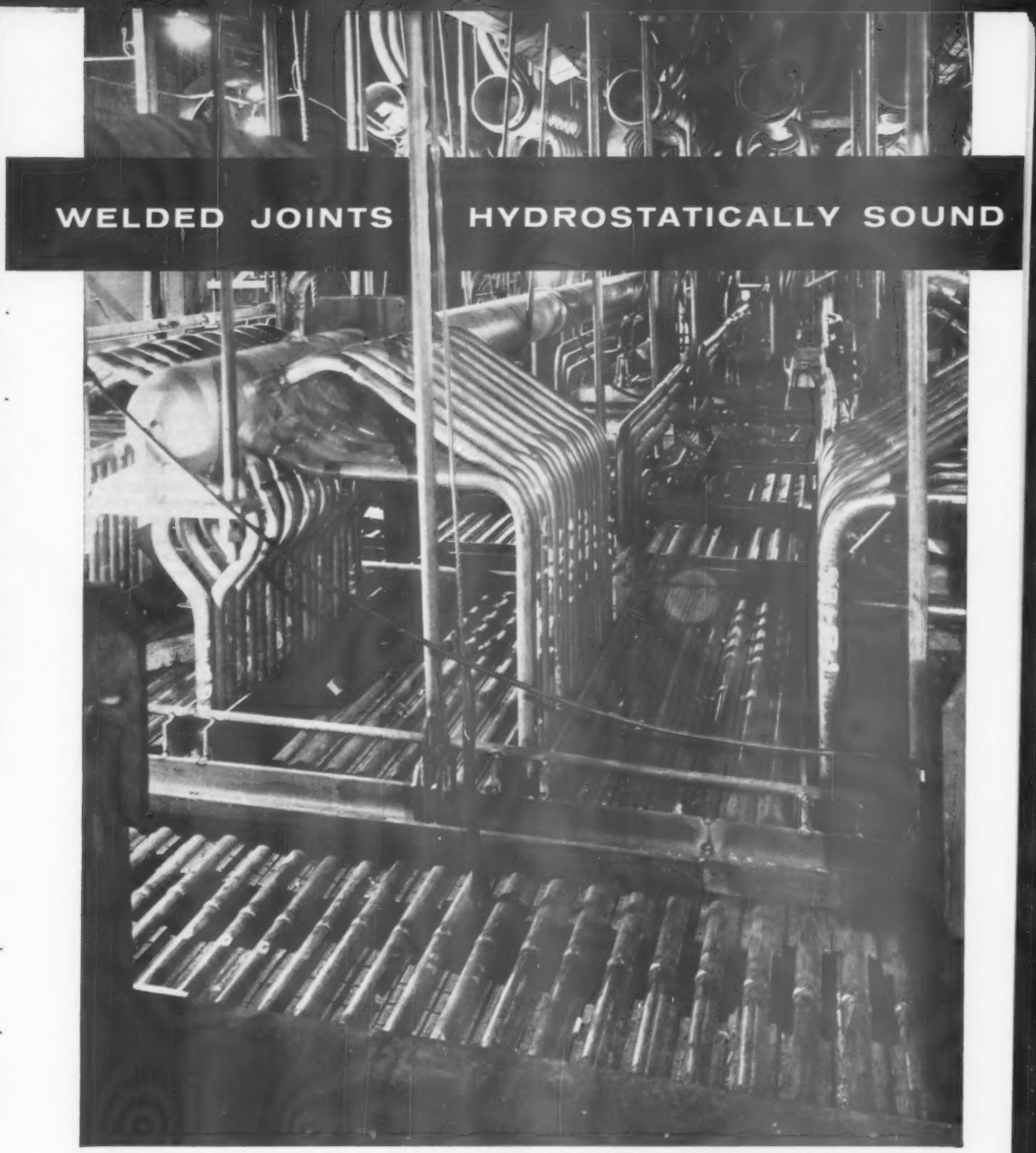
55,000 welds were used to fabricate the hundreds of miles of tubing and piping used in the construction of the steam generating unit. Approximately 25,000 of these were field welds made at the construction site. The extreme operating pressure and temperature necessarily required unusually high weld metal quality and reliability from the electrodes selected. For the field welds, Combustion Engineering, designer and manufacturer of Eddystone's No. 1 boiler, specified Arcaloy types 316 and 347 stainless steel electrodes for the chromium-nickel material, Atom·Arc 8018CM and 9018CM iron powder low hydrogen electrodes for the chrome-moly grades and Atom·Arc 7018Mo for the carbon-moly grades. Continuous visual inspection was conducted as all welding proceeded. Dye penetrant and X-ray inspection of welds were used throughout the erection of the boiler. When the boiler had been completely welded, it was hydrostatically tested at 8,000 psi. pressure. All of these tests and inspections failed to show one defective or leaking field weld.

These dynamic results mirror the experiences of many leading fabricators throughout the country. Like Combustion Engineering, they have proven conclusively that X-ray quality weld metal of Alloy Rods Company electrodes increases the efficiency of their welding operations. They have learned from experience—you can profit from their experience. Specifying your electrode requirements from our extensive line of quality alloy arc welding electrodes is the one sure guarantee of satisfaction. Alloy Rods Company, York 3, Pennsylvania.



The steam producing heart of the station is a C-E Sulzer Monotube Steam Generator, designed and manufactured by Combustion Engineering. This unit is 12 stories high, 100 feet across, and 75 feet from front to back. 170 miles of all-welded tubing and piping, low-chromium and chromium-nickel material, went into the unit's fabrication.

For details, circle No. 12 on Reader Information Card



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TWENTY YEARS OF LEADERSHIP IN THE DEVELOPMENT OF QUALITY ALLOY ARC WELDING ELECTRODES

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"IT ISN'T MUD" . . .

Title of the talk by H. F. Reid at the Northern New York Section meeting on April 6th was "It Isn't Mud." Left to right are W. A. Owczarski, C. H. Kreischer, Mr. Reid and J. Cuturilo

is doing, as well as the progress the district is making, and the things to be accomplished.

Henry James, chief engineer of Sciaky Bros. Inc., spoke on electron beam welding and its uses. He gave a historical background and a very good description of the process. Slides were used along with welded samples.

Ohio

WELDING PROMOTION

Cincinnati—Promoting April as "National Welded Products Month," provided an excellent field of activity for the *Cincinnati* Section. A special committee was formed with Frank Smith, Carl Hanna and Harry Baker. The committee secured a proclamation signed by Mayor Walton Bachrach, proclaiming April as "National Welded Products Month" in Cincinnati, secured a small writeup in the *Cincinnati Enquirer*, got a plug in on the news broadcast over Channel 12, WKRC-TV and succeeded in having a large window sign in the display window of Baker Welding Supply. Additional emphasis was given by Jim McLain, special activities chairman, who secured special signs for distribution in appliance stores, department stores and hardware stores. The signs were of Jim's design and were placed by various members of the Section.

Mayor Bachrach was given an all white welder's face mask with his name printed across the top and "National Welded Products Month, April 1961" across the bottom. In addition, he was also given a pair of welder's leather gloves. The Mayor was quite elated over the gift of the face mask and expressed many uses for it that were not directly connected with welding.

The February meeting was exceptionally large and was highlighted by a visit to the General Electric Jet Engine Plant at Evendale, Ohio. Not only members of the Section, but all of those interested in welding were invited and all found the trip well worth while. Various steps of manufacture including assembly, test, tear-down and reassembly were witnessed not only for the straight jet engine, but also for the turbo-fan engine.

J. R. Wirt, Processing Engineer, Delco Remy Div., General Motors Corp., discussed "What About Ultrasonic Welding?" to an attentive group at the March meeting. Mr. Wirt augmented his delivery with slides and unusual welded samples. The topic was quite interesting because there are some excellent applications for ultrasonic welding in certain phases of manufacturing in the Cincinnati area.

SYMPOSIUM

Cincinnati—The *Cincinnati* Section completed, on April 5th, a successful first symposium on Welding Metallurgy with Dr. Warren F. Savage and Dr. Ernest F. Nippes, of Rensselaer Polytechnic Institute, Troy, N. Y., directing the study. Registrations totaled approximately 200 for the first meeting and averaged between 160 and 175 for each of the following three meetings.

The symposium was organized around four meetings beginning on March 15th and continuing on each Wednesday evening following, terminating on April 5th. The lectures started at 7:00 P.M., included a Coca Cola break midway in the lecture, and then terminated around 10:00 P.M. The meetings were held in an excellently equipped auditorium in the General Electric Co. Jet Engine Plant at Evendale, Ohio.

The lectures were so arranged that Dr. Savage conducted the first two and then Dr. Nippes followed through for the last two. Dr. Savage took the subjects "Basic Metallurgy" and "Practical Welding Metallurgy." Dr. Nippes continued with "Non-Ferrous Welding Metallurgy" and "Ferrous Welding Metallurgy." Mimeographed lecture notes were furnished for the first two lectures along with the new AWS booklet, *Welding Metallurgy*. The price of the booklet was inincluded in the registration fee.

SYRACUSE WELDING COURSE

Instructors and participants in welding course conducted by Syracuse Section. Instructors and national officers in front row (left to right) are F. Feduska, National Membership Chairman H. Miller, M. Schaeffer, National Vice President C. E. Jackson, J. Helmer, W. Hughes and B. Strough

Even though each lecture was approximately 3 hr long, everyone maintained active attention throughout each lecture. Dr. Savage particularly spiked his lectures with his unusual humor and stories even though one woman, Miss Betty Myers, was the only female registrant.

Success of the meetings may be attributed to a small but efficient committee which organized the symposium and carried out its publicity. A special printed brochure was used as the direct mailing piece and was sent out in two mailings, with the first mailing approximately three weeks before the first lecture and then a second or follow-up mailing about one week before the first meeting. Members, industries using welding, and other offices where welding of any kind fitted into their study, received the mailing pieces. This was augmented by articles in the local newspapers and local radio spot announcements.

Stan Weiss served superbly as the Chairman of the Symposium Committee and he was diligently assisted by Dick Kutchera, Larry Mecklenborg, Harold Bartholomew and Harold Kaiser who headed the Telephone Committee. Then each meeting required the splendid assistance from volunteers of the Section.

BATTELLE TOUR

Columbus—On Friday, April 14th, members and guests of the *Columbus* Section held a dinner meeting at the Florentine Restaurant. Del Conklin presented a check for the United Engineering Center Building Fund contributed by student members at Ohio State University. Glen Faulkner of Battelle Memorial Institute discussed the tour that was planned for the evening.

A tour was made through Battelle's Metals Joining Laboratories. Color movies, with accompanying narration, were shown. These movies revealed some of the characteristics associated with the welding arc. Actual experiments in hot tension were conducted for the tour members. The nature of research in resistance welding was discussed and demonstrated. Electron beam welding was explained and shown. After a few introductory remarks, titanium plate was welded in a controlled-atmosphere chamber.

A display exhibited numerous interesting samples of welding, brazing and soldering. The display included metallographic cross sections that showed the alterations that occur in some metals after welding. Photomicrographs illustrated weld metal defects. Automatic welding machines for stationary and rotating pipes were observed. The operation of a machine for drop weight tests on welded steel at subnormal temperatures was seen.

Comments received from the participants after the tour indicated that the evening was a success.

ALUMINUM WELDING

Dayton—The sixth meeting of the 1960–61 season of the *Dayton* Section was held at Kuntz's Cafe. There were 25 members present to enjoy the social hour and dinner.

A half-hour film on American Freedoms preceded the speaker, Howard Adkins, welding specialist currently associated with Kaiser Aluminum and Chemical Sales, Inc. His talk covered the welding of aluminum.

The talk, aided by the use of slides, covered the various aluminum alloys and the numbering system used to determine the alloy. He discussed the type filler material to be used for a specific alloy to gain certain characteristics.

In the field of inert-gas metal-arc and inert-gas tungsten-arc welding, he stressed the importance of clean material and the proper application of shielding gases. Hydrogen introduced into the shielding gas was the greatest cause of weld porosity. A film in slow motion showed weld disposition under good and adverse conditions.

The talk came to a close with a film showing the various uses of welded aluminum alloys.

STUDENTS "CHIP IN"

Del Conklin (left), on behalf of the Ohio State University students, presents check for United Engineering Center to Charles Meinhart at Columbus Section meeting on April 14th

ELECTRODE COATINGS

Bucyrus—A joint meeting of the *North Central Ohio* and *Columbus* Sections was held on Friday, March 10th, at the American Legion

CINCINNATI EDUCATIONAL LECTURE SERIES

Associate Professor W. F. Savage and Professor E. P. Nippes of Rensselaer Polytechnic were co-lecturers at four sessions sponsored by the Cincinnati Section. Shown (left to right) are S. Weiss, L. Mecklenborg, Dr. Savage and M. Levinstein

Intense interest was evident on the part of all who attended the lectures presented by Drs. Savage and Nippes. A typical scene is registered here as audience listens to Dr. Nippes

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That's what everybody seems to be saying wherever the M&T Murex AC Industrial Arc Welder gets put on the job. No wonder. It's designed for easy handling and dependable service, with . . .

Just one inch of shunt travel for entire current range. Rigidly mounted shunt for quiet, chatter-free operation. Fast, single crank heat control. Patented dual-coil transformer in a balanced circuit for smooth, steady arc under all welding conditions. High open circuit voltages for instant starting of arc with all types of electrodes.

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Home in Bucyrus.

Speaker at the technical meeting was Harry F. Reid, manager of Technical Service Division, The McKay Co., York, Pa. Mr. Reid presented an excellent lecture on the historical development of electrode coatings in the arc welding industry. He pointed out how the basic specifications had to be met to conform to AWS classifications.

From the most basic coatings to the present powdered iron types were discussed with a look of semiautomatic electrodes with the cored wires, with and without the requirement of a gas shield. In his basic analysis he pointed out that the coating of mild steel electrodes determined the type of electrode that would result from the standpoint of whether it was to be an a-c or d-c electrode, although the core wire for both might be the same.

His presentation was especially effective by the use of slides to supplement his lecture.

WELDED JOINT DESIGN

Toledo—During the month of March the *Toledo* Section held its annual lecture series in the new Engineering Building of Toledo University.

Four guest speakers participated in this event, and discussed the general subject of "Joint Design for Welding." More than 300 members and guests attended the series.

On March 2nd, H. E. Adkins, district engineer for Kaiser Aluminum & Chemical Sales, Inc., gave an excellent talk on proper selection of aluminum alloys, wires and joint design.

The second lecture, on March 9th, was given by Robert Wilson, vice president of The Lincoln Electric Co. His subject pertained to cost reductions through proper joint design in structural fabrication.

On March 16th, Ted Schmidt, regional manager, Eutectic Welding Alloys Corp., discussed welding and brazing of thin materials.

The fourth and final lecture on March 23rd was delivered by L. J. Christensen, welding engineer for Chicago Bridge & Iron Co. He discussed special problems and basic joint designs as related to pressure vessels and piping.

Pennsylvania

DEMONSTRATION NIGHT

Easton—The *Lehigh Valley* Section held a Demonstration Night on April 3 in the Engineering Building Testing Laboratory of Lafayette College.

An estimated 500 men viewed the exhibits and witnessed the demonstrations of the latest developments in welded equipment.

Manufacturers representatives displayed and used equipment to show such techniques as constricted tungsten-arc cutting, micro-wire welding, tungsten inert-gas spot welding, Innershield semiautomatic process and Vis-arc torches.

The exhibit was held from 7:30 to 9:30 P.M. and every demonstration was viewed with great interest.

Rhode Island

PRODUCTION BRAZING

Providence—The *Providence* Section held its monthly dinner meeting on March 15th at Johnson's Hummocks. William Weber, sales engineer for Handy & Harman, gave an interesting talk on the latest developments in production brazing and the various brazing alloys used today in industry.

He stressed the six steps for good silver brazing procedure as follows: proper cleaning, proper fit and clearance, proper fluxing, proper jigging, proper heating and final cleaning.

A color, sound movie on the subject followed the talk.

FIELD TRIP

Attleboro—On April 12th, the *Providence* Section sponsored a field trip to Metals & Controls Division of Texas Instruments, Inc., Attle-

TOKEN OF APPRECIATION . . .

Toledo Section Chairman J. Barker (right) presents gift to H. E. Adkins, one of four guest lecturers, who spoke on aluminum welding. Other lecturers on other evenings were: R. A. Wilson, The Lincoln Electric Co.; T. Schmidt, Eutectic Welding Alloys Corp.; and L. J. Christensen, Chicago Bridge & Iron Co.

HOLSTON VALLEY GUEST SPEAKER

Don Bertossa discussing high-strength integral vacuum bonding at February 21st meeting of Holston Valley Section

boro, Mass. Ninety members and guests were conducted on a tour of the Spencer, General Plate and Nuclear Divisions. Many interesting processes of assembly, fabrication and welding were observed.

An excellent dinner was served in the plant cafeteria where a Section meeting followed. An interesting movie was shown of processes and automation in Texas Instrument Plants.

The final tour was made of the Nuclear Division and the Welding Laboratory.

Tennessee

VACUUM BONDING

Kingsport—The *Holston Valley* Section held its regular monthly meeting on February 21st at Skoby's Restaurant in Kingsport.

After a brief business session, program chairman Larry Long introduced the speaker for the evening, Don Bertossa of the Chicago Bridge and Iron Co., Birmingham, Ala. Mr. Bertossa's informative talk on the subject of "High-Strength Integral Vacuum Bonding" and the Hortonclad process was supplemented by slides.

His talk included such important points as the process of vacuum bonding, welding of clad materials and testing. He pointed out the difference between clad and lined vessels, also the advantages of using clad material in corrosive service. He also pointed out how clad material can be made in various shapes.

Mr. Bertossa's talk was very educational and was enjoyed by all.

BRAZING CHALLENGE

Johnson City—The *Holston Valley* Section held its regular monthly meeting on March 21 at the John Sevier Hotel in Johnson City.

Speaker of the evening was Donald C. Herrschaft, assistant manager, Brazing Products Div., Handy & Harman, New York, N. Y. The title of his talk was "Brazing Challenges the Thermal Barrier."

Mr. Herrschaft discussed the history of brazing and metals from early times to the present, including the honeycomb brazing for the aircraft industry, problems of producing brazes for elevated temperature service, what available alloys can do, and predictions of where tomorrow's brazing alloys will be obtained.

SEMANTICS

Nashville—Following dinner and a brief business meeting, the *Nashville* Section met on March 9th at the Biltmore Restaurant for its regular monthly meeting.

Dr. Maxwell C. Lancaster, professor of Romance Languages at Vanderbilt University, Nashville, presented a most interesting discourse on "Welding in Eight Different Languages and Welding of Words."

ELECTRON BEAM WELDING

Oak Ridge—The April technical session closed out the technical program for the 1960–61 season of the *Northeast Tennessee* Section. This turned out to be the best attended meeting for the year in that the gathering of technical and sales people exceeded the total membership. The meeting was held at the Oak Terrace on April 13th.

Alexander Lesnewich of the Development Laboratories of Air Re-

"We're using M&T's new DC machine ...it's the best we've seen, and we looked..."

And if *you* look and compare, you'll concur. The Murex 3-phase DC Welder offers the type of rectifier that works best for this service; and it features a design that simplifies operation, makes life easy for the weldor.

Silicon diodes, hermetically sealed, are non-aging and give as much as 98% efficiency. Electrical circuit is designed for instant recovery voltage so that arcs are easily struck, stabilized, and maintained. Simple knob and selector make control of heat and polarity very easy.

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Suitable for manual, automatic, inert gas (MIG, TIG), and spot welding—with quick changeover from one to the other. Plug-in timers for gas pre-flow, post-flow, high frequency drop-out, spot arc. Patented, dual windings in saturable shunt transformer. Sealed non-aging silicon rectifiers for highest efficiency. Want to hear more about M&T's welders?

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A GUEST SPEAKER WITH FRIENDS

A. Lesnewich is shown after being greeted by three Northeast Tennessee Section members at the April 13th meeting. Left to right are L. Marks, A. Lesnewich, W. R. McGrew and R. G. Gilliland

duction Sales Co. presented a well-prepared talk on the principles of operation of the electron beam welding equipment and its application in the metal fabrication industry.

Presently, welding machines are being built in the low voltage range, 15,000–30,000 v, and the high voltage range of 100 to 150 kv. The advantages of the low voltage equipment are (1) no shielding required for x-ray protection and (2) cost. Penetrating ability of the electron beam of the low voltage welding unit is about $^3/_8$ in. thick stainless steel maximum, while the high voltage units can penetrate at least $^3/_4$ in. thick stainless steel. Of course, the high voltage units require shielding for x-rays produced by the high voltage electron beam bombarding the joint or target. The power supply and shielding required for the high voltage equipment makes it a sizable capital investment.

Mr. Lesnewich showed a slide containing a schematic drawing which converted the electron beam machine into a melting furnace for powder alloys or metals. The powder was fed into a water-cooled copper ingot mold at a fixed rate. A defocused beam is utilized to produce melting over the entire area of the cavity of the mold. Presently, the process is limited to very small size ingots of about $^1/_4$ to $^1/_2$ in. diam.

Zone refinement with the electron beam equipment is accomplished by using a circular type filament whereby the rod travels through the circular filament downward at a predetermined rate.

Texas

PIPE MILL TOUR

Orange—The March meeting of the *Houston* Section was a plant visit to the American Bridge Div., United Steel Corp., Orange, Tex. On March 15th, approximately 90 members rode two chartered Greyhound busses to Orange, 120 miles from Houston, where they were met by officers and directors of the Sabine Section at the Little Mexico Restaurant where a very nice dinner was served.

After dinner, they again boarded the busses for a short ride to the plant and were welcomed by L. R. Thomas, plant manager. Guides were furnished for groups of ten, and the next 2 hr were spent

EARLY EVENING

E. Mai (left) and J. Collins (center) greet Guest Speaker R. Culbertson, at April meeting of North Texas Section

touring the new modern plant which has a pipe mill, machine shop, plate shop, marine ways and a structural shop. While some of the operations were not working on the second shift, the visitors were able to see various sizes of pressure vessels and also structural work consisting of huge fabricated beams and girders. One of the most interesting jobs viewed by the group was a huge 34-ft drain tunnel being fabricated for the Maryland-Virginia area near Baltimore. A unique "ferris wheel" was being employed to fabricate the huge sections of the tunnel. The inner and outer sections are then assembled on a way that was formerly used to launch destroyers. The tunnel sections are then launched in approximately 300 ft sections and towed in tandem by tug to the Baltimore area from Orange.

The group returned to Houston on the Greyhound bus, arriving at 11:30 P.M. Everyone making the trip agreed the March meeting was one of the most successful and interesting of the year.

SUPER ALLOYS

Dallas—On Wednesday, April 12th, the regular monthly meeting of the *North Texas* Section was held at Howard Johnson's Turnpike Restaurant.

R. P. Culbertson, Haynes Stellite Co., Kokomo, Ind., was the featured speaker for the evening. Using slides, Mr. Culbertson presented a very interesting talk on welding super alloys.

Thrity-three members and guests were present. Honored guests were six past chairmen of the section: W. A. Thompson '50–'51; R. W. McClaine, '52–'53; George Mays, '55–'56; C. L. Moss, III, '57–'58; Albert Bernson, '58–'59; and F. C. Nordquist, '59–'60.

COVERED ELECTRODES

San Antonio—The *San Antonio* Section met on Monday, April 3rd, at Capt. Jim's with 55 members and guests present. Roy Zuniga, a student at Fox Technical High School, San Antonio, was selected the most outstanding welding student in the South Texas Area and was presented a trophy for this achievement.

Wilbur H. McGrew of the Air Reduction Sales Co. was guest speaker. He presented a most interesting program on "Coated Electrodes," using a series of slides which explained the early history of the cellulose coated welding rod. It was interesting to note the disposition rates in pounds per hour for the various classifications and sizes of welding rods. Another series of slides dealt with the cost of deposited metal. Members were very receptive to Mr. McGrew's presentation on the economics of welding, since this is a point of interest to all companies and users.

Chairman Fred W. Smith announced the excellent window displays sponsored by two of the city's largest department stores in observance of "National Welded Products Month." An official proclamation was signed by Mayor J. Edwin Kuykendall declaring April Welded Products Month in San Antonio.

Utah

HARD SURFACING

Salt Lake City—The March meeting of the *Salt Lake City* Section

FOX VALLEY PANELISTS

Semiautomatic panelists at the March 17th meeting of the Fox Valley Section were (left to right) J. Jezwinski, J. Wiegand, H. Treleven, J. Teigen and M. Kern

"Mighty convenient to get all our welding accessories with just one call to M&T..."

A one-stop supply source for every arc welding need—that's M&T. The Murex line of accessories is wide. It offers the finest quality to be had. It assures you proper service.

You name the items—M&T will supply them: electrode holders • cables • ground clamps • helmets • durable gloves, etc.

And don't forget these: a thousand types and sizes of electrodes including iron powder, low hydrogen, and stainless. And the complete range of welding equipment including gas engine welders, AC machines, rectifiers and AC-DC units.

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A SPEAKER

J. J. Calaman who spoke on jet piercing at Madison-Beloit Section March 16th meeting

consisted of a very interesting talk by William L. Lutes of the McKay Co. The subject of his talk was "Hard Facing." Mr. Lutes is author and co-author of papers on various applications for hard surfacing materials.

A social hour and dinner preceded the meeting held at the Panorama Inn.

Wisconsin

PANEL DISCUSSION

Hollandtown—The *Fox Valley* Section tried something new for the section in the way of meetings and was very pleased with the result. It had had panel discussions before, once with a panel from outside the section membership and once with member talent. Results were so outstanding when using member talent that it was decided to use this talent again. The "new" aspect was the method. To gain more time for audience participation and questions, the moderator, Robert King, vice president of Manitowoc Shipbuilding, Inc., introduced the panel, their respective backgrounds, work their company specializes in, and the welding equipment used. He established the subject "Practical Applications of Semiautomatic Welding" and proceeded to solicit audience-panel discussion. The panel consisted of John Teigen, Overly's, Inc., Max Kern, Appleton Structural Steel Co.; John Wiegand, Valley Iron Works Corp.; Joe Jezwinski, Berlin Chapman Co.; and Harold Treleven, Damrow Bros. Co.

So many valuable points were brought to light that it would be impossible to enumerate all of them. Some that stand out, however, include the point that many factors other than the performance of the equipment must be considered when evaluating a given semiautomatic process. Mr. Wiegand noted that since his company had started using a CO_2 process, patchup work in the machine shop had been eliminated. Mr. Jezwinski noted that setting up equipment for a given job may negate the savings over stick electrodes. Mr. Treleven noted the need of eliminating build-up of weld deposit by semiautomatic welding of light gage stainless. Mr. Teigen pointed out several items to consider when selecting a piece of equipment or a process. Mr. Kern discussed the problems of distortion in welding structural steel with semiautomatic and automatic processes.

The meeting was held on March 17th at Van Abel's in Hollandtown.

PAST CHAIRMEN

Some of the past section chairmen who were honored at the Milwaukee Section meeting on March 17th

JET PIERCING

Madison—On Thursday evening, March 16th, 52 members of the *Madison-Beloit* Section, and their guests, met at the Eagles Club House for what turned out to be one of the Section's highlights of the year. The usual dinner type meeting got underway at 6:30 P.M. At 8 o'clock the speaker for the evening was introduced. Neither the speaker or his topic was directly associated with welding. However, interest and enthusiasm ran high through the entire evening.

J. J. Calaman, regional engineer for the Linde Co. in Minneapolis, Minn., showed slides and spoke on the subject of jet-piercing as it applies to taconite in iron-ore mining. This process is the only known method today of piercing blastholes with a jet flame. This is accomplished with a 55-ft long oxy-fuel oil torch. Mr. Calaman is really one of the "fathers" of this impressive process and, therefore, knows his topic well. He was capable of taking his audience step-by-step from the very beginning to the present where it becomes quite routine to pulverize as much as seven acres of taconite at one time. Furthermore, great strides are being made in the use of this process in the cutting of granite. This process is becoming so popular that countries from all over the world are sending rock samples to the Linde Laboratories to see if their rocks might be severed using this new and rapid process.

PAST CHAIRMAN'S NIGHT

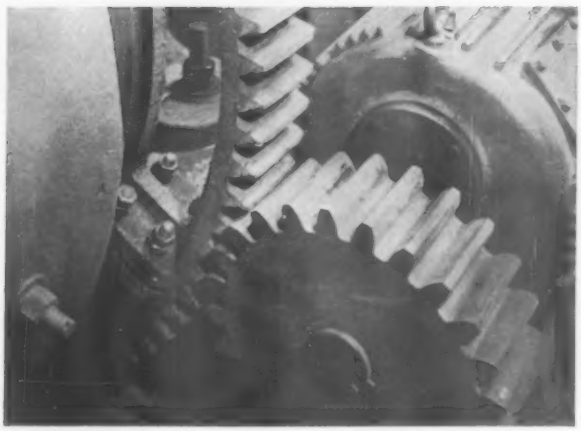
Milwaukee—The March 17th "Past Chairman's Night" of the *Milwaukee* Section was honored with the presence of thirteen past chairmen.

The coffee speaker was Chuck Arps of the Public Relations Dept., Allis Chalmers Mfg. Co. His topic was "How Do You Expect to Rate if You Don't Communicate." Mr. Arps was a very dynamic speaker and left the audience with the feeling that much improvement has been made in public relations.

The technical speaker was Coyle Case, welding engineer of Huntington Alloy Products, Div. of International Nickel Co. He was a substitute speaker for Mr. Spicer who was unable to attend. His subject for the evening was "The Welding of Nickel, High Nickel Alloys in the Nuclear Industry." He gave a brief history of nickel alloys, pointing out the difficulties which had arisen during their experimental stages of welding.

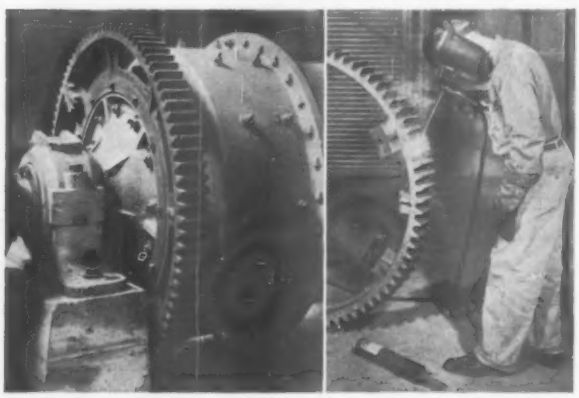
Much emphasis was placed on the fact that, because of the rigid requirements of the Navy, greater strides in the welding of high nickel alloy materials have been made in the last three years than was made in the previous ten-year period.

Mr. Case covered briefly the welding of Inconel and the importance of cleanness of the parent metal. It was his feeling that the welding rods developed for the welding of high nickel steels should be of such a nature that it should not be necessary to rely to any great extent upon special techniques of the operator.



Colmonoy Hard-Surfacing Makes Spur Gears Last Thirty-five Times Longer

Spur gear life of 5000 hours is now obtained by the operator of the ball mill shown, instead of a previous gear life of only 140 hours. The reason for this tremendous jump in service life: The application of Colmonoy No. 2 hard-surfacing electrodes to the gear teeth. And it costs less to hard-surface a worn gear than to buy a new one!



Gear wear was accentuated because this mill processes hard compounds, causing extremely abrasive particles to fall on the meshing gear teeth.

Protecting spur gear teeth by arc welding deposits of Colmonoy No. 2. These low-hydrogen DC electrodes weld fast, require low amperages.

Wherever excessive metallic wear exists, there is an opportunity to cut costs. You know where such wear exists. Colmonoy sales engineers know what to do about it. Call one. Or write to Detroit about your problem part.

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New Members

EFFECTIVE APRIL 1, 1961

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	204
Members	6,537
Associate Members	5,837
Students	361
Honorary Members	10
Life Members	31
Total	12,980

ALBUQUERQUE

Bingham, K. E. (C)
Craytor, G. Gail (C)
Sims, Paul (B)

BATON ROUGE

Millburn, Rufus M. (C)

BIRMINGHAM

Talley, Otis (C)

BOSTON

Chase, Preston (C)
Crowley, Leo E. (D)
Griggs, Edward W. (D)
Hall, Franklin J., Jr. (D)
Jumpe, James G. (D)
McEachern, Richard (D)
Meyers, Donald E. (B)
Poole, John W. (C)
Tagliani, Louis E. (D)

CAROLINA

Cassels, John W., Sr. (B)
Taylor, James E. (C)

CHICAGO

Christianson, George J. (B)
Jancy, Edward J. (C)
Pfeiffer, Merven, N. (C)
Roberts, Kenneth B. (B)
Sandberg, Harold R. (B)
Setzekorn, Gene M. (B)
Stiscak, George J. (D)
Tustin, Thomas (B)
Wick, Rudolph William (B)

CINCINNATI

Capizzi, Thomas J. (C)
Graham, Donald Charles (C)
Heileman, Harry J. (C)
Robinson, F. E. (B)
Root, Charles W. (C)
Smith, William Charles (C)

CLEVELAND

Cooley, Kenton P., Jr. (B)
Griffin, Robert C. (B)

COLORADO

Masiker, Dick H. (C)

COLUMBUS

Diniaco, Marcus Phillip (C)
Frazier, James Hogg, Jr. (D)
Stone, John G. (C)

DAYTON

Sanders, Gordon L. (C)

DETROIT

Ballentine, C. B. (C)
Evans, Roger B. (B)
Kasl, James M. (C)
Kelsey, Arthur F. (C)
Planting, Charles O. (B)
Sterling, Bruce (B)

EASTERN ILLINOIS

Muirhead, Robert J. (B)
Walter, William R., Jr. (B)

GREATER HUNTSVILLE

Barnett, James H. (B)
Brosemer, C. A. (C)
Burns, Thomas H. (B)
Cagle, Virgil Lee (C)
Case, George D. (B)
Catlett, James F. (B)
Craig, C. A. (C)
Cresap, John (B)
Davis, Richard A. (C)
Eisenhardt, Otto K. (B)
Gayle, Walter G. (C)
Graser, R. F. (B)
Green, C. L. (B)
Harrison, Fred L. (C)
Hoppes, Robert V. (C)
House, Jewell G. (C)
Huang, Dick M. C. (C)
Islamoff, Ilia I. (B)
Johnson, Rayburn G. (C)
Kobler, Ruth S. (B)
Kocsis, Laszlo (B)
Lauderdall, Jack B. (C)
McCaig, James C. (C)
Miller, I. B. (C)
Mincher, George W. (C)
Proszek, Mack F. (B)
Raitch, Alexander J. (B)
Russell, W. B. (B)
Sexton, F. J. (C)
Verble, Nolen (B)
Wallace, Paul B. (B)
Werner, Leonard (B)
Wilson, Edward J., Jr. (B)
Wilson, Robert Q. (C)
Worthington, J. A. (C)

HARTFORD

Falcone, A. S. (C)

HAWAII

Anson, Michael A. (B)
Auerbach, Kelly (C)
Chun, Tai Yee (C)
Elliott, Wm. R. (C)
Gonsalves, George L. (C)
Guy, Douglas E. (B)
Helenihi, Wallace M. K. (D)
Hipp, Henry Lai (B)
Horner, John E. (C)
Hymel, Ben A. (B)
Kaalele, Charles K., Jr. (D)
Kalima, Henry (D)
Laurance, W. R. (C)
Law, Herbert H. (C)
Lee, J. T. (C)
Leite, George (C)
Lindley, Carroll (B)
Lum, Kai (C)
Machado, Richard R. (B)
Manhoff, Milton (C)
Matsumoto, Richard M. (C)
Matsushima, Michael (B)
Medeiros, Alvin (B)
Muraoka, Nelson H. (B)
Pahukula, Joel (D)
Parker, Howard W. (B)
Patterson, Charles A., Jr. (C)
Pauls, Louis P. (B)
Saunders, David H. (C)
Sigler, Charles N. (C)
Silvey, David R. (C)
Stacy, J. F. (B)
White, Robert Nuel, Jr. (C)
Yamanaka, Jack T. (C)

HOUSTON

Janes, John N. (B)
Pennell, Roy A. (B)
Wilson, Andrew (B)

INDIANA

Isgrigg, Gilbert (B)

IOWA

Gibson, Frank (C)

IOWA-ILLINOIS

Cunningham, L. S. (B)

J. A. K.

Christophersen, Harold A. (C)
Hilburn, Herbert M. (B)
Ressler, Bernard G. (C)

LONG BEACH

Brugger, Ralph E. (C)
Hausen, Arthur C. (C)
Wells, Sam G. (B)

LONG ISLAND

Lopez, Antonio (B)

LOS ANGELES

Dyer, Gerald E. (B)
Fairbanks, Robert (D)
Froby, Howard M. (B)
Gaw, William D. (D)
Heady, Paul A., Jr. (D)
Kent, Anthony R. (D)
Laird, Robert M. (D)
Morse, William J. (B)
Nishimoto, Lloyd T. (D)
Warner, William M. (D)
Woods, R. L. (D)

LOUISVILLE

Dodge, Gerald F., III (C)

MADISON-BELOIT

Harmsen, Carl Herman (D)

MAHONING VALLEY

Walker, Kenneth S. (B)

MARYLAND

Virden, Robert Charles (C)

MILWAUKEE

Browne, Hardwick L. (C)
Faust, William A. (B)
Gersch, Michael J. (B)
Hanisch, William C. (B)
Stubbe, James S. (C)

NEW JERSEY

Soled, Julius (B)

NEW YORK

Agnello, Jack C. (C)
Galbraith, J. F. (B)
Hallock, Oliver W. (C)
Johnson, Evan A. (A)
Katz, Lyber (B)
Macdonald, Cornelius J. (C)
Midboe, Albert (C)
Park, John W. (B)
Parker, Theron D. (B)

NIAGARA FRONTIER

Pettit, Paul H. (D)
Pierce, Milton F. (A)
Roberts, Worthington P. (C)

NORTH TEXAS

Laakman, Frank A. (C)
McCown, J. W. (B)
Ter Meer, Theodore J. (B)

NORTHEAST TENN.

Donnelly, Ralph G. (C)

NORTHERN NEW YORK

Savidge, Roland E. (B)

NORTHWEST

Marquette, Donald G. (C)
Schulze, Howard T. (B)

PEORIA

Bogener, E. L. (C)
Brooks, Carl D. (B)
Hobbs, Gerald R. (B)
Morsch, Nick R. (C)
Van Den Arend, Robert A. (C)

PHILADELPHIA

Buckley, David H. (C)
Whitcomb, N. E. (B)

PITTSBURGH

Borland, Thomas E. (B)
Crabb, Charles E. (C)
Kinsey, Donald W. (C)
Kohl, William R. (C)
Matthews, Dave (B)

PROVIDENCE

Winslow, Donald L. (B)

PUGET SOUND

Anderson, William A. (C)
Hart, Norman R. (B)

ROCHESTER

Krupnicki, Theodore A. (B)

SAGINAW VALLEY

Mandeville, David E. (D)

ST. LOUIS

Faltus, Arthur V. (B)
Morrison, R. D. (B)

SALT LAKE CITY

Bennett, Lamoine (D)
Caulfield, James H. (B)
Christensen, La Voy S. (B)
Shoemake, Matthew J. (B)

SAN ANTONIO

Oberg, Ronney (D)

SAN FRANCISCO

Armstrong, James G. (B)
Kenney, William E. (B)
Smith, Warren C. (B)
Spitoni, A. L. (B)

SANTA CLARA VALLEY

Carson, Kent R. (D)
Donnelly, Wm. D. (D)
Durling, Richard K. (D)
Hendra, David C. (B)
Razavi, Iradj (D)
Ruiz, Joe (D)

SOUTH FLORIDA

Butler, N. T., Jr. (B)

STARK CENTRAL

Boni, Frank, Jr. (B)

SUSQUEHANNA VALLEY

Valentine, Raymond T. (B)

SYRACUSE

Dodson, Henry, Jr. (B)
Hughes, Rupert D. (C)
Moebs, John T. (B)
Stead, George (B)

TRI-CITIES

Henders, Orma L., Jr. (B)

TULSA

Goodridge, J. Lee (B)

WASHINGTON, D. C.

Gibson, H. C., Jr. (C)
Reed, Frank, Jr. (B)
Schweizer, Rudolph (C)
Warren, Robert J. (C)

WESTERN MASSACHUSETTS

Wieland, Donald F. (C)

WESTERN MICHIGAN

O'Malley, John Kevin (C)
Strazanac, William M. (C)

WORCESTER

Swenson, Howard E. (B)

YORK-CENTRAL PA.

Jensen, K. H. (C)

MEMBERS NOT IN SECTIONS

Brown, Reubin Henry (C)
Shah, D. A. (C)
Tucker, Donald M. (C)

Reclassifications During April, 1961

CLEVELAND

Roberts, Robert Suttie (C to B)

GREATER HUNTSVILLE

Daley, Daniel M., Jr. (C to B)
Dawson, James K. (D to B)

NIAGARA FRONTIER

Blewett, James (C to B)

PORTLAND

Froehlich, Robert (D to C)

SANTA CLARA VALLEY

Vancotti, Leonard R. (D to C)

MEMBERS NOT IN SECTIONS

Venci, Alessandro (C to B)

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For midwest manufacturer of production fusion welding machines. Must have experience in mass production techniques and automatic welding process applications. Ability to visualize methods of process mechanization, and to prepare quotations, specifications, and negotiations with customer through sales representatives is required. Age 30–35. Only applicants possessing these qualifications will be considered.

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Physical metallurgist for work on problems associated with the petroleum and chemical industries. Research group develop welding techniques for pressure vessel construction, select materials of construction, and investigate service failures. A degree in physical metallurgy required. Some experience in welding desirable. Age to 35.

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NEWS of the industry

Welding Refresher Course

Hobart Welding School, Troy, Ohio, will again conduct one week welding refresher courses for Industrial Arts and Vocational Agricultural teachers during the months of June, July and August 1961.

These courses are for teachers who feel the need to brush up on their welding techniques and keep abreast of the new developments in manual, automatic and semi-automatic arc welding.

For complete information write to Hobart Bros. Technical School, Troy, Ohio, and ask for Bulletin J-11280.

Federal Machine Merges with McKay

Federal Machine and Welder Co., Warren, Ohio, is to be completely merged with its parent company, The McKay Machine Co., Youngstown. Stockholder approval of the plan was obtained in annual meetings recently, and actual merger of the two local firms needs only state approval.

The Warren firm, a subsidiary of McKay since November 1960, will be known as the Federal-Warco Division of McKay Machine Co., after the merger is completed. It will, however, retain its present management, personnel and facilities.

In other actions, McKay shareholders appointed Federal's vice president and treasurer, Ralph N. Letizell, to be a vice president of McKay, and re-elected all other present officers and directors.

Welding Topic Featured at AISE Spring Conference

"Recent Developments in Welding Techniques for Mill Maintenance" was one of the principal topics at the Association of Iron and Steel Engineers Spring Technical Conference, in St. Louis, April 24th, 25th and 26th. The paper was given by Robert A. Wilson, vice president, The Lincoln Electric Co., Cleveland.

Wilson's paper discussed improvements in techniques and developments in equipment that can be used to get the most out of a surfacing program. Specific applications were reviewed to illustrate surfacing problems as they concern rolling mill equipment and how they can be approached to obtain maximum results at lowest cost.

Handy & Harman Moves Headquarters

Handy & Harman, the nation's largest fabricator and refiner of gold, silver and other precious metals, recently moved its executive offices after 94 years of transacting business in the New York's traditional financial district in lower Manhattan. On May 8th, the company relocated at 850 Third Ave., New York, in new executive offices which, according to J. C. Travis, president, "will enable us to better serve our increasing number of customers in many areas of industry. Our new offices will be designed and located for maximum efficiency and convenience. In making this important move this firm will be joining the ranks of many of America's outstanding companies on Third Ave., which is rapidly becoming a corporate center for American industry."

Jackson Products Moves

Jackson Products, Air Reduction Sales Co., has moved its entire manufacturing operation to a new plant at 5523 Nine Mile Rd., Warren, Mich. Jackson gains a 100% increase in floor space in their new facility, a contemporary style building on a 195,000 sq ft site one mile north of Detroit, Mich.

Need for greater research and

design facilities and more warehousing space prompted this fourth move in the company's 27 year history. The $4^1/_2$-mile move caused no change in personnel and virtually no loss of production.

COMING EVENTS

A Calendar of Welding Activity

ISA

June 6–8. Summer Instrument-Automation Conference and Exhibit. Royal York Hotel and Queen Elizabeth Hall, Toronto, Ont., Canada.

June 28–30. 2nd Joint Automatic Control Conference. University of Colorado, Boulder, Colo.

NEMA

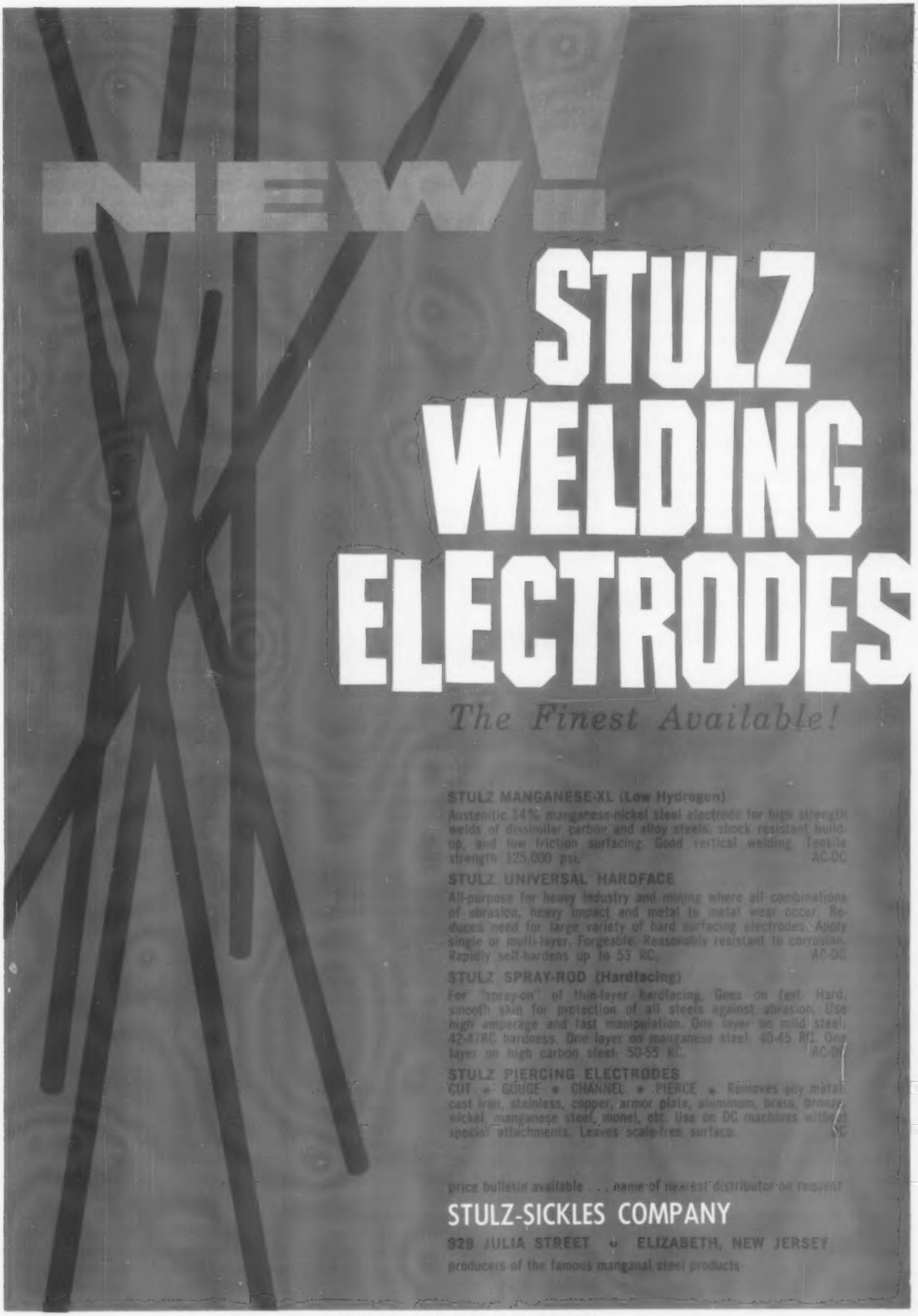
June 8–9. First Western Conference, Biltmore Hotel, Los Angeles, Calif.

ASTM

June 25–30. Annual Meeting. Chalfonte-Haddon Hall, Atlantic City, N. J.

AWS

Sept. 25–28. 1961 National Fall Meeting. Hotel Adolphus, Dallas, Tex.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The Finest Available!
STULZ MANGANESE-XL (Low Hydrogen)
Austenitic 14% manganese-nickel steel electrode for high strength welds of dissimilar carbon and alloy steels, shock resistant build-up, and low friction surfacing. Good vertical welding. Tensile strength 125,000 psi. AC-DC
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All-purpose for heavy industry and mining where all combinations of abrasion, heavy impact and metal to metal wear occur. Reduces need for large variety of hard surfacing electrodes. Apply single or multi-layer. Forgeable. Reasonably resistant to corrosion. Rapidly self-hardens up to 53 RC. AC-DC
STULZ SPRAY-ROD (Hardfacing)
For "spray-on" of thin layer hardfacing. Goes on fast. Hard, smooth skin for protection of all steels against abrasion. Use high amperage and fast manipulation. One layer on mild steel: 42-47RC hardness. One layer on manganese steel: 40-45 RC. One layer on high carbon steel: 50-55 RC. AC-DC
STULZ PIERCING ELECTRODES
CUT • GOUGE • CHANNEL • PIERCE • Removes any metal: cast iron, stainless, copper, armor plate, aluminum, brass, bronze, nickel, manganese steel, monel, etc. Use on DC machines without special attachments. Leaves scale-free surface. DC
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For details, circle No. 20 on Reader Information Card

American Cryogenics Expands

With the purchase of the Burdett Oxygen Company's California facilities, plus the leasing of Victor Equipment Company's manufacturing plants in La Habra and Sacramento, Calif., the California Oxygen Co. (Calox) of American Cryogenics Corp. has now become the largest independent producer of liquid and gaseous oxygen, nitrogen, argon, and acetylene and hydrogen gases in the 11 western states.

According to Pierce E. Marks, Sr., president of the American Cryogenics, the California acquisitions, with their large tonnage plants for the manufacture of these gases, is another step in the continued diversification of the American Cryogenics operation.

Pullman Signs with Matisa

Pullman-Standard, division of Pullman, Inc., recently announced the signing of an agreement with the Matisa Equipment Corp., Chicago Heights, Ill., under which Matisa will act as sole agent for the sale of Pullman-Standard's line of railroad track maintenance machines in the United States.

Linde Supplies On-site Oxygen for Ozone Processing

On-site oxygen moved into another chemical processing application last week as Linde Co., Div. of Union Carbide Corp., completed its new oxygen plant at Emery Industries, Inc., in Cincinnati, Ohio. This is the first on-site plant designed to produce high-purity oxygen for conversion to ozone.

Emery Industries is the nation's largest producer of ozone, which it uses for the oxidation of oleic acid to produce such derivatives as pelargonic and azelaic acids. Linde's new on-site plant replaces the liquid oxygen supply system previously employed by Emery and provides sufficient capacity to supply a second, larger ozone oxidation plant now nearing completion at Emery's Ivorydale location.

Welding in Shipbuilding

The Autumn Meeting of the Institute of Welding in England this year will take the form of an International Symposium on Welding in Shipbuilding, organized jointly in association with the Royal Institution of Naval Architects, the Institute of Marine Engineers, the North East Coast Institution of Engineers and Shipbuilders, and the Institution of Engineers and Shipbuilders in Scotland.

There will be more than thirty technical papers, covering all aspects of the design and construction of welded ships and of the quality control of ship welding, including contributions from the leading British shipyards and from Denmark, Germany, Holland, Italy, Japan, Poland, Sweden and the United States of America.

The meeting will be held in London from October 30th to November 3rd, 1961.

Gulf Coast Air Separation Plants

The Gulf Coast is the scene of two new air separation plants opened by Air Reduction Sales Co. at Tampa, Fla., and Baton Rouge, La. Airco's expansion in this area is in response to the burgeoning of industry in the South, especially in the Gulf Coast area and Florida.

Liquefied gas production began on March 15th at the Tampa plant

(shown), while at Baton Rouge production has been underway since last June. Each of the two plants, together with related distribution equipment, represents a multimillion dollar investment.

Liquefied industrial gases—oxygen, nitrogen and argon—are being supplied by the plants to growing industries in the areas. These include petroleum and petrochemical producers in Texas and Louisiana, citrus processors in Florida, and metalworking factories, shipyards, electronic manufacturers, hospitals and military posts throughout the Gulf Coast states.

Submarine Contracts

Definitive contracts were awarded to two firms which in February received letter contracts for construction of Polaris missile submarines of the Lafayette class.

Electric Boat Div., General Dynamics Corp., Groton, Conn., received a definitive contract for two submarines with a total maximum price of $76,200,000. The contract provides for future conversion to an incentive-type contract.

Newport News Shipbuilding & Drydock Co., Newport News, Va., received a definitive contract for two submarines with a total maximum price redeterminable downward of $75,314,000.

School for Supervisory Personnel

Short workshop courses designed to upgrade the ability of key personnel to direct, control and evaluate fusion welding operations are being conducted by Hobart Brothers Technical School, Troy, Ohio.

Supervisors, inspectors, plant managers, welding foremen and engineers are studying preheating and stress relieving, welding fundamentals for supervisors and en-

gineers, arc-welding inspection and quality control, automatic welding and gas shielded arc welding processes. The school is run on a twice a month basis with one-week courses. Classes, which begin at 8 A.M. and last till 4 P.M. are open to management people who are interested in advanced welding production techniques. Registration Bulletin DM-168 includes a description and schedule of classes. For more information, write to Hobart Brothers Technical School, Troy, Ohio.

Groman Addresses Bridge Operators

R. H. Groman [illegible], director of training and applied engineering, Eutectic Welding Alloys Corp., Flushing, N. Y., addressed the annual meeting of the Bridge Operators Engineering and Inspection Service organization on March 17th in the Hotel Duluth, Duluth, Minn.

Groman's subject was "The Welding of Crane Rails," a subject of vital interest to the assembly.

First Large-capacity Liquid Helium Plant

Linde Co., Div. of Union Carbide Corp., recently announced that it will build a liquid helium plant at Amarillo, Tex. The plant will have a capacity of 100 liters per hr of

liquid helium, the largest such commercial production unit in the United States.

IAA Holds Annual Convention

Highlights of the two-day meeting of the International Acetylene Association at the Sheraton-Plaza Hotel in Boston, April 24th and 25th were technical sessions on the use and handling of cryogenic fluids and safety and safe practices in oxy-acetylene applications. The meeting, which was held this year for the first time in Boston, was the 63rd Anniversary Convention of the IAA, one of the oldest technical societies in the country.

Alberta Firm Changes Name

"NCG Canada Limited" is the new name of the firm previously known as Alberta Oxygen & Acetylene Co., Ltd. The company is a subsidiary of Chemetron Corp.

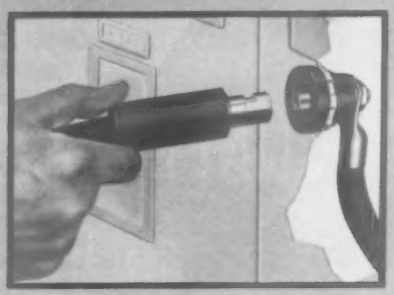
R. L. McDougall, general manager, said the shorter, easier-to-remember new name is descriptive of the company's widening activities in marketing NCG product lines of Chemetron's National Cylinder Gas Div., which include welding and cutting equipment and supplies and inhalation therapy and other medical apparatus.

Stress Relieving Furnace Installed

Meriam-Weld Div., Meriam Instrument Co., 112th St. at Madison, Cleveland 2, Ohio, recently announced the installation of a new fully instrumented stress-relieving furnace. Closely controlled heat-

ing and cooling cycles should assure that finished weldments will possess inherent stability and, when machined, will hold very close tolerances. Combined with completely modern electronic flame cutting, welding and fine shot blasting facilities, the new equipment produces precision weldments.

Specify



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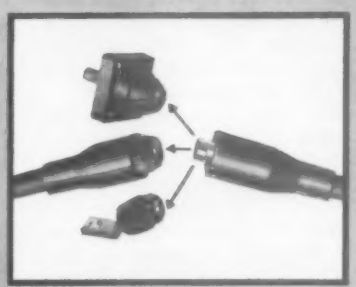
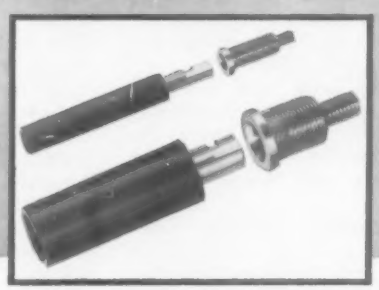
- FORNEY
- OMARK-GRAHAM
- KSM PRODS.
- MID-STATES
- BRENWELD
- BIRDSELL PRODS.
- HUGHES AIRCRAFT CO. (Vacuum Tube Products Div.)

. . . and many others





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For details, circle No. 21 on Reader Information Card

PERSONNEL

Jacklin Advances

Announcement was recently made by Miller Electric Manufacturing Co., Appleton, Wis., of the appointment of Gordon Jacklin AWS to the post of assistant sales manager.

Jacklin has been with Miller since 1951.

Eutectic Advances Doyle

Howard E. Doyle AWS has been named Regional Manager in the North Central States area for Eutectic Welding Alloys Corp., Flushing, N. Y., manufacturer of welding, brazing and soldering alloys for maintenance and repair.

Doyle has been with Eutectic since 1953, as a technical representative in Northern Illinois and in St. Paul. In 1960 he was named Field Supervisor in the North Central area.

Doyle studied Business Administration at the University of Wisconsin and has completed intensive technical courses given by Eutectic. He is well-known as the conductor of many Welding Training Programs in schools and industrial plants in the North Central area.

Dwyer to New Post

Miller Electric Manufacturing Co., Appleton, Wis., manufacturer of arc and spot welders, recently announced the promotion of John R. Dwyer AWS to assistant to C. Burnell Abel, vice president in charge of sales. Dwyer's new assignment is in addition to his present responsibility for the solicitation and administration of government defense contracts and supervision of certain prime contracts.

Dwyer, who has been with Miller Electric since 1956, is a native of Kendall, Wis., and a graduate of the state university.

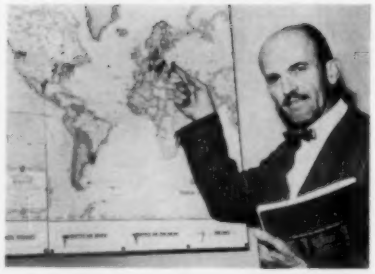
Engineer to Publish in Russian Journal

A prolific part-time wordsmith and full-time engineer at Hanford has the distinction of being the first known writer at the Atomic Energy Commission's plutonium plant to be published in Russian.

Eugene LaVelle AWS, a welding engineer in General Electric's Construction Engineering and Utilities Operation, lists 32 technical papers on the subject of welding already published or accepted for printing in the United States and abroad. His works so far have been translated into Japanese, Spanish, French, German and Italian, with foreign language editions due shortly in Russian, Polish and Rumanian.

LaVelle got word this year from Kiev, Russia, that a Soviet welding publication planned to print one of his articles in the near future.

In the past two years the busy author's papers have been presented in sessions of the International Institute of Welding in Vienna, Austria and Opatija, Yugoslavia. In addition, the Hanford writer has given numerous oral presentations on welding cities in the East, Pacific Northwest and at most of the larger AEC sites.



Eugene LaVelle

LaVelle, who squeezes his writing into his off-duty hours, is currently working on the following projects: a book on inert gas welding for the American Society for Metals and the National Research Institute for Metals in Tokyo, Japan; a chapter on nuclear power for the AMERICAN WELDING SOCIETY HANDBOOK; a paper on welding problems in nuclear reactors for the International Atomic Energy Agency; and two papers co-authored with other scientists.

Blanchard Named for Controllers Institute

Edward M. Blanchard, treasurer for the Arcos Corp., Philadelphia, Pa., was recently elected a director of the Controllers Institute of America. He was chosen during the organization's Eastern Area Conference at the Shoreham Hotel, Washington, D. C.

Mr. Blanchard, who has been active in the controllers' group since 1951, is immediate past president of its Philadelphia Control.

Established in 1931, the Institute is a nonprofit management organization of controllers and finance officers from all lines of business—banking, manufacturing, distribution, utilities, transportation, etc.

Gordon Jacklin

H. E. Doyle

John R. Dwyer

British Appointments

R. P. Newman, has been appointed Head of the Members' Service Dept. of the British Welding Research Assn. in succession to P. H. R. Lane, who has been appointed Director of Research of the Drop Forging Research Association. T. R. Gurney, will succeed Newman in charge of Fatigue Researches at the British Welding Research Association.

Chyle and Scheil Among Five Honored

Five men widely known in engineering and industry, four of them graduates of the University of Wisconsin and three of them leaders in Wisconsin industry, were cited for outstanding accomplishments in their fields at the 13th annual Wisconsin Engineers' Day celebration May 5th.

The five engineering-industry leaders were recommended for distinguished service citations by the UW College of Engineering faculty and Pres. Conrad A. Elvehjem, and the recommendations were approved by the University's Board of Reagents meeting.

The citations were awarded to: John J. Chyle AWS, director of welding research, A. O. Smith Corp., Milwaukee, and past president of the American Welding Society; William T. Ennor, Aluminum Co. of America, New Kensington, Pa.; Oswald J. Muegge, Wisconsin State Board of Health, Madison; Merrill A. Scheil AWS, director of metallurgical research, A. O. Smith Corp., Milwaukee; and Frederick M. Young, Young Radiator Co., Racine.

Borst and Fraser Elected Directors

George E. Borst of Philadelphia and Edward S. Fraser AWS of Hinsdale, Ill., have been elected directors of Chicago Bridge & Iron Co., world wide steel plate fabricating and construction firm with corporate headquarters in Chicago.

They succeed H. C. Brown of New York and Donald A. Leach of Ottawa, Ill., both of whom retired following many distinguished years as officers and directors of the company.

Mr. Borst, a company vice president, is manager of CB&I's eastern sales region. Mr. Fraser is CB&I's vice president in charge of manufacturing. He joined the company as an engineer in 1939, shortly after his graduation from the University of Illinois with a B.S. degree in Civil Engineering. He was appointed manager of the company's Salt Lake fabricating plant in 1950, assistant sales manager in 1957 and was elected manufacturing vice president in 1960.

Battelle Appoints Hicks

Dr. John F. G. Hicks has been named associate director of Battelle Memorial Institute according to a recent announcement by Dr. B. D. Thomas, president.

Formerly vice president of the Corning Glass Works and vice president and technical director of Corning Glass International, Dr. Hicks is a chemist with broad experience in industrial research and development and in corporate management. A former National Research Fellow and Research Associate at Massachusetts Institute of Technology, he first became associated with Corning in 1938 as a research chemist and, in 1943, was granted leave of absence to work on the Manhattan Project at Columbia University of Oak Ridge, Tenn.

Lacy Joins Alloy Rods

Robert L. Lacy recently joined the sales staff of the Hard Surfacing Division of Alloy Rods Co., York, Pa. F. L. Blodgett, General Manager of this division, announced that Lacy, a District Manager, will headquarter at the Company's Chicago sales office and will cover the mid-western region of the country as a specialist in hard surfacing.

Lincoln Electric Transfers Evans

Lincoln Electric Co., Cleveland, Ohio, has announced the transfer of Samuel R. Evans from Philadelphia to its Buffalo, New York, sales territory.

Evans, a graduate of Ohio Wesleyan University with a B.A. degree in Mathematics and Purdue University with a B.S. degree in Electrical Engineering, came to Lincoln in 1955. After one year of intensive training in the application of arc welding and welding equipment, he was appointed to Lincoln's staff of field engineers and assigned to the Philadelphia office. This position was held until the time of his transfer to Buffalo.

Westinghouse Names Robbins

James R. Robbins has been appointed product line manager of electrodes and brazing for the Westing-Arc Dept., Westinghouse Electric Corp., Buffalo, N. Y.

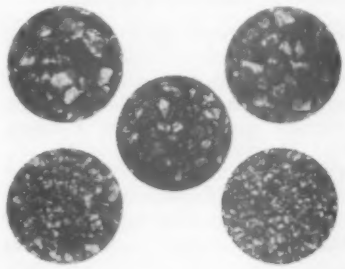
Mr. Robbins began his career with Westing-Arc as a sales engineer in

development of a highly advanced, new process for producing hard metals.

CLEC-ITE

granular tungsten carbide

the leader of CleMet Products' new line of hard metals



5 uniform grain sizes of improved toughness and high strength

- Maximum abrasion-resistance
- For application in the petroleum, agriculture, construction and mining industries whose equipment is subject to extremely rugged, abrasive duty.

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For details, circle No. 22 on Reader Information Card

the Richmond, Va., territory. Prior to joining Westinghouse, he was vice president and general manager of Welder's Supply Corp., Richmond, Va. His welding experience covers a period of nearly 15 years.

Alloy Rods Appoints Clark

H. D. Clark has joined the Alloy Rods Co. sales force in the New England states area. E. R. Walsh, III AWS, vice president in charge of sales, states that Clark, originally a New Englander, will headquarter in Waltham, Mass.

Chemetron Honors Employees

Fifteen veteran employees of the Chemetron Corp., NCG Div., were given gold watches and welcomed into the Chemetron 25-Year Club at a recent dinner in the Pearson Hotel, Chicago, Ill.

Charles J. Haines, Chemetron chairman, presented the watches and membership plaques to Eugene A. Hackett and Donald C. Wilson AWS, general office; Joseph E. DeCoste AWS and Merle W. Hammond AWS, research; and Charles F. Holtz and Frank J. Pecha, Chicago district sales.

Awards also were presented by Haines to Ora L. Spriggs, recently retired; Harold A. Hansen and Joseph R. Peterka, Milwaukee NCG plant; and Albert A. Arakelian, George J. Heinzel, Omar L. Hill, John A. Metlin, Walter H. Rubel and Everett F. Wagner of National Cylinder Gas Div. plants in Chicago, Ill.

Bastian-Blessing Selects Owen

The appointment of Russell E. Owen as advertising manager for the Bastian-Blessing Co. was recently announced by A. L. Augur, president.

Owen, formerly manager of marketing for Day-Brite Lighting, Inc., in St. Louis, Mo., will be responsible for advertising, sales promotion and public relations activities for the company with headquarters in Chicago, Ill.

Burke Selected

The Fibre-Metal Products Co., Chester, Pa., recently announced the appointment of Donald R. Burke as acting comptroller. He will have full responsibility for all accounting phases of the business. Burke is a certified Public Accountant in Pennsylvania and a member of the Pennsylvania Institute of C.P.A.'s.

He was formerly with William H. Gills, Inc., and with the M&T Co. of Philadelphia.

METALLURGICAL MANAGER

Metallurgical Manager—B.S.—M.S., with demonstrated administrative and technical ability. Position involves managing and directing the activities of a modern metallurgical and welding laboratory engaged in both the ferrous and non-ferrous fields. This laboratory performs an important function in the operation of a large, integrated facility engaged in both product development and production activities.

A management position that offers a challenging responsibility for the individual interested in a western location. Send complete resume and requirements to:

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High speed Cutting Electrode slices through cast iron machine housing. This one low-cost electrode cuts any ferrous alloy, lowers inventories.

the versatile electrodes for field work to JOIN · CUT · SHAPE

Used extensively in construction • road building • farming mining • job shops • maintenance work

STEELARC® is All-State's specially coated electrode for all mild steel work —flat, vertical, overhead positions. Pass on pass without slag removal. AC or DC. One rod inventory.

All-State CUTTING ELECTRODE for fast, economical arc cutting of steel, cast iron, stainless, high chrome armor plate. AC or DC.

All-State CHAMFER ROD for chamfering, gouging, bevelling, routing and channeling without oxygen or air. Made with special compounded flux coating to protect rod and speed work. AC or DC.

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QUALITY WITH SERVICE

For details, circle No. 23 on Reader Information Card

F. L. LaQue on ASA Council

F. L. LaQue, vice-president and manager of the Development and Research Div., International Nickel Co., Inc., was recently appointed as one of three representatives of the American Society for Testing Materials on the Standards Council of the American Standards Association for a term expiring in 1963.

Mr. LaQue is a past-president of the ASTM.

Davis Appointed at Bastian-Blessing

The appointment of G. Douglas Davis as Manager—New Product and Market Development at The Bastian-Blessing Co. has been announced by A. L. Augur, president.

Davis, formerly advertising manager, will be responsible for the coordination of all new product activities.

EMPLOYMENT SERVICE BULLETIN

Services Available

A-744. Electric Welding supervisor —technician—inspector. 25 years experience. Manual—semi-automatic—automatic. Familiar with ASME-Navy specifications. Pressure—nuclear—turbine—tanks, etc. Plus X-ray magnetic—partical—Zyglo and Dye-penetrant.

A-746. Welding Metallurgist. R & D, staff or quality control. Graduate courses in metallurgy. Publications and patent. 18 years experience in welding evaluation and development of aluminum alloys. Arc, electrical resistance and ultrasonic welding. Material fabrication through testing welded structures. Correlation and interpretation of welding and material variables with nondestructive tests, microstructure, mechanical and corrosion properties.

Evans Appointed Research Manager

International Harvester has announced the appointment of Charles D. Evans AWS as manager of Manufacturing Research. Since 1953 he has been assistant manager of the facility and now succeeds W. D. Bryson, who has been elected a vice president of Solar Aircraft Co., an International Harvester subsidiary.

During his career, Evans has been active on numerous technical committees, having served as Industry Coordinator of the Ordnance Advisory Committee on the Welding of Armor and Chairman of the Technical Activities Committee of the American Welding Society. He is presently a member of the AWS Welding Handbook Committee.

Metalweld Appointment

S. John Oechsle, Jr. AWS, President of Metalweld, Inc., announced the recent appointment of Walter T. Senkowski as General Manager of the Industrial Maintenance Div.

In his new capacity, Senkowski will direct the industrial maintenance operation but will continue to devote the major portion of his time to the activities as vice president of M-W Equipment Co.—the firm construction and industrial equipment division.

Townsend Named Regional Manager

T. H. Townsend, Jr., has been appointed regional manager for the Pure Carbonic Company's central region according to a recent announcement by G. C. Cusack, president. Central region headquarters are located in Cleveland, Ohio. In his new post, Mr. Townsend will direct all of the company's marketing, distribution and field office administration operations in the states of Ohio, Michigan, Eastern Indiana, West Virginia, Kentucky and Western Pennsylvania.

OBITUARY

Mansfield M. Griffith

Mansfield M. Griffith, welding engineer, died at his home in San Jose, Calif., on March 5th. He was 48 years old.

M. M. Griffith

Griffith, at the time of his death, had been with the Food Machinery & Chemical Corp., Ordnance Div., for 10 years as chief welding engineer and welding consultant. His activities included welding concept and design, research and production. He also had acted in the capacity of welding consultant for various affiliate corporation divisions. He was responsible for welding techniques used in connection with the various armored personnel carriers produced by the Ordnance Div. at San Jose, Calif., for the Army and Navy and various missile ground handling equipment.

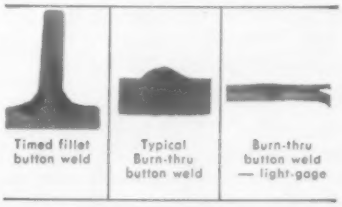
Griffith was a member of the AWS in the Santa Clara Valley Section.

C-OMANUAL button welding boosts output . . . cuts rejects

Here's one button the zipper hasn't replaced. In fact, this button process is the latest development in welding — a development that has replaced old-fashioned spot-resistance welding and riveting.

Armed with a lightweight hand gun using A. O. Smith's CO_2 C-OMANUAL process, the operator works from one side only. The button burns through to fasten steel up to 3/16 in the downhand position and 3/64 in the vertical. And welders take their helmets off to button welding — no need to wear one with this A. O. Smith process. Simple, too! Special operator training is not required. Just place the gun . . . pull the trigger! Hold until the welding stops *automatically*. Perfect button weld every time . . . no flux to clean.

Choice of nozzles permits welding of any of the standard joints (lap, fillet, butt).



Other button blessings include quality low-hydrogen weld metal, high deposition rates, full utilization of weld metal for low overall costs. Put this high-speed production tool to work for you. Send for Bulletin MW-253 for details.

Through research . . . a better way

A.O.Smith CORPORATION

WELDING PRODUCTS DIVISION

Milwaukee 1, Wisconsin

A.O. Smith INTERNATIONAL S.A., Milwaukee 1, Wis. U.S.A.

For details, circle No. 24 on Reader Information Card

New Literature

Preheating, Stress-Relieving

Many preheating and stress-relieving problems can be solved with the aid of 400-cycle induction heating booklet, EW-294, partly published by Hobart Brothers Co., Troy, Ohio.

This 32-page 16-section booklet answers many of the questions about why, when and what to preheat and stress relieve. Sections include information on demand for stress relieving, when to stress relieve, the purpose of stress relieving, program of stress relieving, types of post-heat treatments for welded joints, preheating before welding, methods of stress relieving, frequencies for induction heating, controlled programming, definitions and references, typical stress-relief treatments for certain ferrous alloys, stress relieving as specified in "Rules for Construction of Unfired Pressure Vessels" from the ASME Boiler Construction Code, induction heating coil construction, attaching thermocouples, how to make or repair a thermocouple and trouble shooting guide.

For your free copy, circle No. 51 on Reader Information Card.

Inspection Manual for Hot Dip Galvanized Products

American Zinc Institute, Inc., 292 Madison Ave., New York 17, N. Y., has just released a new and definitive inspection manual governing protective zinc coatings on products hot dip galvanized after fabrication that is intended to prove an invaluable aid to product inspectors, designers, as well as the galvanizing industry itself.

Entitled: "Inspection Manual for Hot Dip Galvanized Products," the 34-page book has been prepared in cooperation with the American Hot Dip Galvanizers Association, Inc., to help manufacturers achieve optimum corrosion protection from the galvanized coatings on their products. In comprehensive and concise form, the manual describes significant factors governing inspection, properties, specification and purchasing, of hot dip zinc coatings.

Comprehensively illustrated with photographs, charts and graphs, the manual describes the galvanizing process, discussing such significant details as the metallurgical structure of zinc coatings, factors influencing adherence, effects of various conditions of the basic metal, etc.

Said to be of excellent value in guiding product inspectors, the manual establishes criteria for high quality hot dip galvanized coatings, and describes in precise detail reliable methods for testing these. ASTM recommendations for zinc coating weights are listed for different types of products, and a detailed check-list for inspectors' acceptance, rejection and recommended action, are some of the valuable material included in the manual. In addition, the book includes a section on product design and assembly in relation to hot dip galvanizing that reportedly should make the manual a worthwhile desk-side aid to the product designer.

For your free copy, circle No. 52 on Reader Information Card.

Silver Brazing Alloys

A revised and expanded 24-page, "Aircosil Silver Brazing Alloy Manual" has been released by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. Well illustrated and diagrammed, the brochure discusses brazing procedures, problems and solutions.

All Aircosil silver brazing alloys—from those in standard rod forms to the new Aircosil Fluxcor 45 which incorporates the fluxing agent in the center of the wire—are thoroughly discussed, stressing advantages and applications. Easy-to-read diagrams help select the proper Aircosil alloy to meet particular industrial needs.

For your free copy, circle No. 53 on Reader Information Card.

Motor Control

Sciaky Bros., Inc., 4915 W. 67th St., Chicago 38, Ill., has available Bulletin No. 343, describing their Sciakydyne Zero-error Motor control. The control is used where regulated speed and exact positioning are required, such as in missile guidance, numerically controlled machine tools, automatic fusion welding equipment, general automation, material processing and manipulators.

The Sciakydyne Zero-error Motor Control turns a d-c motor into an outstanding, accurately controlled servo-mechanism, and provides a direct link between an a-c power source and a d-c motor. It is within the feed-back family of servo systems.

For your free copy, circle No. 54 on Reader Information Card.

ASTM Books Available

The American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., has announced that two new books are available. The first is the "Index to the Literature on X-ray Spectrographic Analysis," which is the first of a series of bibliographical surveys of the literature of X-ray spectrographic analysis covering 211 references for the years 1913 through 1957. It is a 48-page, paper cover book which sells for $1.50.

"Compilation of Chemical Compositions and Rupture Strengths of Super-Strength Alloys," containing 12 pages at a price of $1.50, is a revision of a report issued in 1955. All known alloys are included.

Copies of these books are available from ASTM headquarters.

Welding Rod Data Charts

A series of reference data charts pertaining to all AMPCO bronze welding electrodes, bare filler rods and wire are being offered by Ampco Metal, Inc., P.O. Box 2004, Milwaukee 1, Wis.

Included in the charts is information on comparative bronze electrodes, melting rates and efficiencies, electrode and filler rod specifications and recommended welding currents for various welding procedures.

The charts also describe the Ampco color code, deposit density, number of electrodes per pound and feet per pound of bare rod and wire.

For your free copy, circle No. 55 on Reader Information Card.

Heavy-Duty A-C, D-C Welding Machines

Six models of the combination a-c, d-c heavy duty industrial metallic arc welder are described in a new bulletin (NH-185) available from the National Cylinder Gas Div. of Chemetron Corp.,

840 N. Michigan Ave., Chicago 11, Ill.

The models provide rated output of 300, 400 and 500 welding amperes at 60% duty cycle, and are available with or without power factor correction. Features are listed in the bulletin, an illustration shows dimensions, and a specifications table gives welding current ranges, power input and other information for each model. Optional running gear is described and illustrated.

For your free copy, circle No. 56 on Reader Information Card.

Welding Report

A new technical report on the metallurgy of electronic welding was recently prepared by the technical staff of Hughes Aircraft Co., 2020 Short St., Oceanside, Calif., and is now available from the company's vacuum tube products division.

The report covers laboratory studies directed by R. D. Engquist, and includes: (*a*) the resistance welding process, (*b*) significant factors in resistance welding, (*c*) evaluation of weldability of various materials, (*d*) weldability of clad materials, (*e*) dissimilar materials.

The report is illustrated with photographs of magnified welds, and includes several charts and graphs.

For your free copy, circle No. 57 on Reader Information Card.

Longitudinal Welding Positioner

Airline Welding and Engineering, 15899 S. San Pedro St., Gardena, Calif. (Box 70), recently announced the availability of Bulletin AW-11-60 which describes the Series 11300 basic longitudinal welding positioner stated to be a vital tool in the aircraft and missile industries.

For your free copy, circle No. 58 on Reader Information Card.

Aluminum Arc Welding Data

The Aluminium Development Assn., 33 Grosvenor St., London, W1, England, has released an Addendum to Bulletin No. 19 (The Arc Welding of Aluminium—1955) which covers "Notes on Process Selection and Filler/Electrode Materials."

This Addendum, which also takes into account the developments of fine-wire welding with the inert-gas metal-arc gun, amplifies those paragraphs of Bulletin No. 19 which deal with the choice of filler rod or electrode to suit the welding of given parent metals. The addition consists of two parts, the first giving further guidance on the choice of welding processes and the second dealing with the appropriate filler or electrode for welding pure aluminum to one of its alloys, or to dissimilar alloys; also for the welding of wrought to cast aluminum.

For details, circle No. 59 on Reader Information Card.

Electrode Directory

Information concerning their full line of arc-welding products is contained in Lincoln Electric Company's (Cleveland 17, Ohio) new bulletin 7000.7 entitled "Weldirectory of Arc Welding Electrodes, Equipment and Supplies." This bulletin presents information on AWS electrode classification and discusses correct electrode selection for every type of welding application. Arc characteristics, welding procedures and physical properties are listed for each electrode including stainless steel, cast iron and hard-surfacing types, as-well-as those designed for mild and low alloy, high tensile steel welding. In addition, the bulletin supplies descriptive information on the performance and construction features of Lincoln's full line of arc welders; including electric and gas engine driven generators, transformer and transformer rectifier designs and welding supplies.

For your free copy, circle No. 60 on Reader Information Card.

Now you can check WELD TIME with new PORTA-COUNT cycle counter

only **$282**

Counts actual weld time during firing. PORTA-COUNT is light and small enough to carry easily—keep right on the job. Completely portable and self-contained with long life (up to 2 years) batteries. Counts single phase.

No Plug In No Clips No Clamps

PORTA-COUNT uses an inductive pick up to count, sensing magnetic field around power line, welding buss, transformer or electrodes.

INSTRUMENT CONTROL CO.
2309 Snelling Avenue
Minneapolis 4, Minnesota

For details, circle No. 26 on Reader Information Card

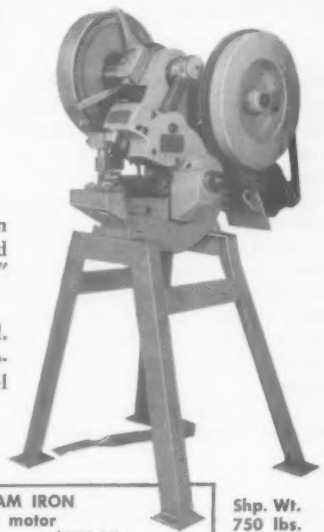
Large and Small Fabricators of steel and ornamental iron swear by it ...

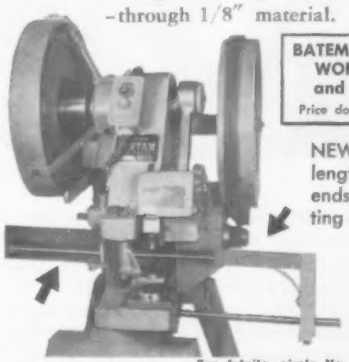
BATEMAN BANTAM IRON WORKER

The Bantam cuts and punches fast and clean . . . no grinding necessary. It's versatile, and saves time and labor! Cuts 2″ x 2″ x 1/4″ angle and 1/4″ x 4″ flats.

Punches 1/2″ hole through 1/4″ material. Operates by hand or foot, uses 3/4 hp motor (1750) rpm., powered with flywheel and drive gear.

The Coper will cope 1-1/4″ –through 1/8″ material.





BATEMAN BANTAM IRON WORKER, with motor and stand $575.00
Price does not include Blades, Punches or dies.

Shp. Wt. 750 lbs.

NEW ACCESSORIES: Gauge for cutting to length, Guide for Flat Bars for cutting on ends, and Angle Iron Trimming Guide, for cutting at a 45 degree. Write for details.

WRITE TODAY for complete information and name of nearest distributor

Bateman Foundry & Machine
MINERAL WELLS, TEXAS

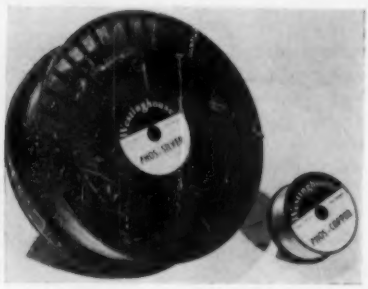
For details, circle No. 25 on Reader Information Card

New Products

Oxyacetylene Brazing Alloys

The Westing-Arc Dept., Westinghouse Electric Corp., Buffalo, N. Y., recently announced that phosphorous-copper and phosphorous-silver brazing alloys, B CuP-2 through B CuP-5, are now available on disposable spools.

The new package is said to permit savings in time and material by making it unnecessary to scrap or



weld short rod ends together. By mounting the spool above, below, or beside an operator, it is possible to pull off the proper amount of wire readily as needed in the joint.

Primarily designed for oxyacetylene brazing, the new package is available in 25-lb spools of 0.035 through $^{3}/_{32}$-in. wire diam, and in $1^{1}/_{2}$-lb spools of 0.035 and 0.047-in. wire diams. The alloys continue to be available, in addition to the spools, in coil, rod, powder and ring form.

For details, circle No. 101 on Reader Information Card.

New Manganese Electrode

A new concept in nickel manganese steel electrodes has been developed by Rexarc, Inc., West Alexandria, Ohio, under the name of Rexarc Manganese Build-Bond. Build-Bond is a composite rod with an all mineral coating designed for the build-up, and/or bonding of austenitic manganese steel.

The chief characteristics of the new electrode include: All position, multiple pass, high deposition, high strength, high ductility, excellent wear resistance. The 100% alloy coating forms a smooth, self-relieving slag that reportedly brushes away easily with a wire brush. No chipping is required. Running nickel manganese electrodes with ease, and getting a smooth, clean deposit without chipping is said to be an outstanding achievement.

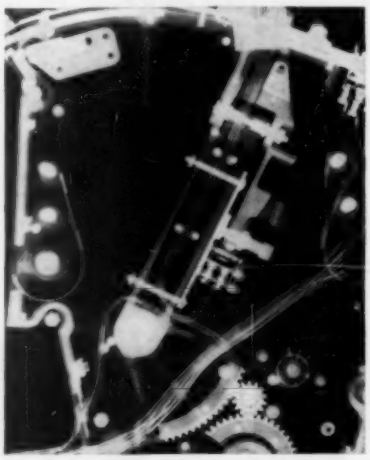
Build-Bond is designed to be outstanding for resisting severe service that combines abrasion and heavy impact. Deposited hardness ranges from 75 to 85 Rockwell B Scale, but work hardens to 45 Rockwell C Scale.

For details, circle No. 102 on Reader Information Card.

Low-Cost X-Ray Paper

An industrial x-ray paper that costs about half as much as standard x-ray film has been introduced by Picker X-Ray Corp., White Plains, N. Y.

The paper, called "CAWO," produces 4 to 6% sensitivity and is



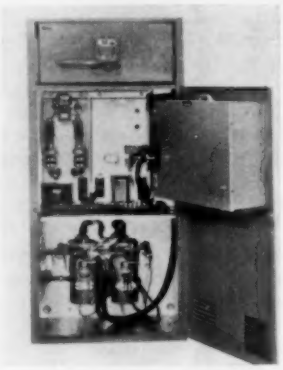
excellent for finding flaws in sharp-contrast items such as electronic assemblies, tires and metal-to-metal bondings, the company said.

CAWO paper can be inspected directly without using special viewing illuminators, because it is a glossy print on a stiff paper base and not a film, it is reported. It is processed in the usual way and yields a durable print free from fogging, according to the company.

For details, circle No. 103 on Reader Information Card.

Completely Transistorized Welder Control

A complete new line of transistorized resistance welder controls which combines better weld quality with minimum maintenance has been introduced by Square D Co., 4041 N. Richards St., Milwaukee 12, Wis. An extension of the Square D Norpak static welder control sys-



tem, the new controls use transistor timing and switching circuits to replace the conventional thyratron timing tubes and switching relays. Typical applications include automatic conveying systems, machine tool control, numerical positioning and other jobs where reliability, high speed and long life are important.

For details, circle No. 104 on Reader Information Card.

Welding Diaphragm Assemblies

A dual welding machine system, recently designed by Thomson Electric Welder Co., 161 Pleasant St., Lynn, Mass., has multiple capabilities: equipment welds the base, spacers and free stems to diaphragm plates of 0.004 in. thick; and then seam welds a tier of up to ten plates in pairs. The machine for assembling the individual components is a 30 kva spot welder tooled with three quick-change electrodes that are precision made to accommodate variable size parts. The second unit, for seal welding a sandwich of two plates and a spacer, a stem or a base, is a 10 kva machine fitted with supporting mechanisms and tooling.

The spot welder measures about 18 x 24 x 28 in. over-all conveniently

Why shout?

We don't make fancy claims, just good electrodes. We take great care in making them. We make all kinds, too.

All we ask is that you try a box. We think you'll be pleased with the way they weld. BUT: If they aren't — in your honest opinion — as good or better than any electrode you've used, bring back the box and we'll give you back your money.

Square deal?

HARNISCHFEGER
Milwaukee 46, Wisconsin

P&H
WELDING PRODUCTS DIVISION

BETTER WELDING THROUGH ARCOS QUALITY CONTROL

X-ray Emission Spectrograph shows analysis of Arcos weld metal

Predictable performance of Arcos weld metal results from strict adherence to uncompromising standards. The program of rigid quality control of filler metal products enforced by Arcos is comprehensive and far-reaching. Every phase in production is subjected to constant inspection. Modern testing instruments provide highly accurate analysis of materials and weld metals. Rigid quality control assures predictable performance of Arcos filler metal products.

ARCOS

Arcos Corporation • 1500 S. 50th St. • Philadelphia 43, Pa.

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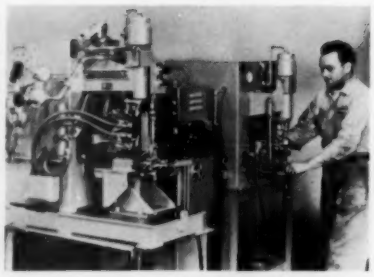


fits on a portable or stationary stand. The 30 kva transformer, water cooled and providing eight points of heat, is located in the rear section of the frame and is easily accessible. A press-type, antifriction head operates by a single acting air cylinder with spring return. Pressure is 700 lb at 80 psi; the piston stroke is $1^{3}/_{4}$ in.

A spring type, ejection mechanism that is built into the upper tip holder facilitates changing the electrode.

On the second machine a maximum of ten diaphragm plates—or five sandwiches—may be stacked and circumferentially seam welded in pairs. Diameters of from $1^{11}/_{16}$ to $2^{1}/_{2}$ in. can be mounted in the same tooling device. This welding unit—a 10 kva model AO-6 measuring 13 x 33 x 33 in.—features a driven lower electrode wheel with variable speed controls, rotational control, fine spray water cooling, and a parts positioning device which, by a variable tensioned spring, permits the operator to seam weld each sandwich in the diaphragm stack without changing horizontal alignment.

For details, circle No. 105 on Reader Information Card.

Hard-surfacing Electrode

A new hard-surfacing electrode for joining such dissimilar metals and hard-to-weld steels as austenitic manganese to carbon steel, austenitic manganese to T-1 steel and stainless steels to carbon steel has been developed by the McKay Co., Pittsburgh 22, Pa.

McKay Hardalloy 120 deposits have a controlled ferrite level of approximately 12%—providing crack resistance equal to armor welding electrodes. The new electrode is a build-up material with high compressive strength and ability to withstand repeated impacts with minimum deformation and no cracking, it is claimed. Corrosion resistance and hot hardness up to 1000° F is reported.

For details, circle No. 106 on Reader Information Card.

Low Cost Welding

A low-priced gas-shielded metal arc welding package is now available to industry through Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. The two-unit Aircomatic MIGet Package provides versatile and high-speed welding of stainless and mild steels and aluminum for the remarkably low cost of $995 (Zone 1 destinations).

The complete package includes a Model AH20-E Aircomatic MIGet Gun and the new MIGet CAV power source.

No separate controls are needed for this new compact package. Instead, the MIGet Gun connects directly to the power source.

Rated at 200 amp, 60% duty cycle, the new MIGet CAV power source was designed especially for the MIGet Gun. It is small, having an over-all length of $34^1/_2$ in.; height of $25^3/_4$ in.; and width of $19^1/_2$ in.

For details, circle No. 107 on Reader Information Card.

Abrasive Supplies

Geoscience Instruments Corp., 142 Maiden Lane, New York 38, N. Y., announces an entirely new line of abrasive supplies for the metallographic and petrographic laboratory. These coated abrasives, grains and flour are especially produced for fine laboratory work.

Geoscience is the first to offer the smaller, more economical 25-unit pack (standard size is 100 units).

For details, circle No. 108 on Reader Information Card.

Safety Lock Clamp

Detroit Stamping Co., 330 Midland Ave., Detroit 3, Mich., has announced a new addition to its line of clamps. Called the "Han-D-Vise" the new tool performs the many duties of a clamp, wrench, vise or plier and will firmly hold any size work up to its maximum jaw opening of $1^1/_4$ in. with a power-

WELD WITH ARCOS STAINLESS ELECTRODES

Job Report Courtesy of Allis-Chalmers Mfg. Co., Milwaukee, Wisconsin

Hydraulic turbine runner blades overlaid to resist cavitation. To protect the blades of this huge hydraulic turbine runner from the destructive effects of water wear, Arcos stainless rods were selected for overlaying critical areas. The precise chemical and metallurgical properties of Arcos stainless rods—assuring uniform, predictable results—make this process both dependable and economical. Meet your stainless welding requirements with Arcos—the most complete selection available anywhere.

ARCOS

Arcos Corporation • 1500 S. 50th St. • Philadelphia 43, Pa.

For details, circle No. 29 on Reader Information Card

ful 1 ton grip—yet releases at the flick of a finger.

Made of high grade, hardened alloy steel with deeply serrated, heat-treated jaws, the Han-D-Vise is copper plated for lasting appearance and resistance to weld splatter. Reportedly ideal for fac-

tory, garage, repair shop and home the nonslip grip and knurled adjustment screw make it the perfect tool for one-hand operation in hard-to-get-at places.

Han-D-Vise is manufactured in 7-in. and 10-in. sizes, with or without quick action trigger release, and is available from the factory or De-Sta-Co's nationwide distributor organizations.

For details, circle No. 109 on Reader Information Card.

Portable Welding Gun

The C-Type Craft Portable Welding Gun is one of a complete line now manufactured, sold and serviced by Kirkhof Manufacturing

Corp., 2450 Buchanan Ave., Grand Rapids, Mich. The new gun line is designed to attain maximum-output on the production line by achieving unusual compactness and ease of handling. In addition to the C-Type gun, the line includes scissors-, bell-crank, expansion- and fixture-type units—all assembled from a minimum of interchangeable, standardized components. This provides maximum adaptability to changing production requirements and makes maintenance of the units both easy and economical.

For details, circle No. 110 on Reader Information Card.

Welding Cable, Hose Protector

The Singer Glove Manufacturing Co., 860 W. Weed St., Chicago 22, Ill., recently announced a neoprene-coated sleeve that is said to practically eliminate costly replacements

and hose and cable repairs in gas welding and in gas-shielded-arc welding. It comes in lengths to fit 9, 12½ and 25 ft standard cable sizes and has a sturdy zipper for easy application. Named C. H. P. (cable and hose protector) the sleeve protects from damage caused by falling objects, trucks and kicks, as well as normal deterioration. By increasing life of cable and hoses it can pay for itself.

For details, circle No. 111 on Reader Information Card.

Arc-Welding Machine

A new series of heavy-duty industrial arc welders for a-c manual and automatic production welding operations has been placed on the market by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. Designated MCM-AC Bumblebee "S" Series, the units come in 300 and 500 amp sizes and have a 60% duty cycle rating.

Employing a transformer with a movable coil design, these Airco welders are said to be among the simplest, most rugged and least expensive industrial arc welders available. More efficient welding is made possible by eliminating magnetic arc blow and permitting the use of larger electrodes and higher heat values. The simple,

mechanically operated, moving coil assures dependable performance, stepless control of welding current and maximum arc response.

For details, circle No. 112 on Reader Information Card.

Welding Machines for Thin Metals

Stored-energy welding equipment designed especially for manufacturers of such precision electronic components as high density packages and welded modules has been developed by the Vacuum Tube Products Div., Hughes Aircraft Co., 2020 Short St., Oceanside, Calif.

According to the company, the complete line includes six different stored-energy power supplies and five different weld heads and handpieces. Sizes and ratings are designed to enable selection of a set-up to meet any of the needs of manufacturers of relays, tubes, transducers, pots, thermocouples and high-density component packages.

The welding power supplies include ultra short discharge time, fully metered controls, input voltage regulation and a packaging concept "that allows all units to be used on standard production benches without need for special installations."

For details, circle No. 113 on Reader Information Card.

Welding Helmets and Handshields

Choice of six welding helmet and two handshield styles is offered in the new Oxweld line introduced by Linde Co., Div. of Union Carbide Corp., 270 Park Ave., New York 17, N. Y. Three shell types—straight, curved and narrow front—are available with either stationary or lift-front glassholders. Handshields are available in straight or curved shell models.

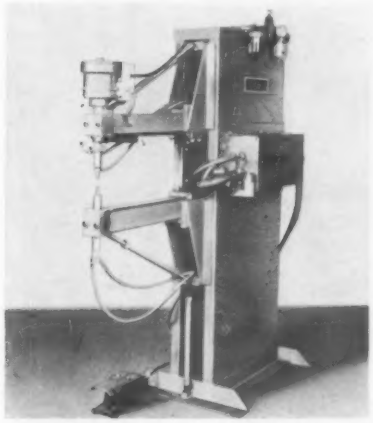
All shells are molded in one, seamless piece from a glass fiber reinforced polyester which is strong and lightweight and has exceptional resistance to sparks, molten metal and flying particles. Headgears are constructed of sturdy plastic and have a simple mechanism for instant, perfect fitting. A "free-floating" suspension system eliminates pressure points for maximum comfort. Plain or hardened filter plates in 12 shades, clear glass and plastic cover plates, and a standard line of replacement parts and accessories are also available.

For details, circle No. 114 on Reader Information Card.

Low Cost Spot-Welding Machine

A new, budget priced spot welder with all the essentials for dependable performance, but stripped of all unnecessary "frills," is now being produced by Viking Products Co., a subsidiary of Progressive Welder and Machine Co., 915 Oakland Ave., Pontiac, Mich.

According to the company this sturdy production spot welder—



first in a new line of economy welding equipment—was designed for general use in both large and small shops where heavy capital investment is impossible. Operating on regular 80-psi line pressure, it developes a clamping force of 1950 lb and has complete lubricator, strainer and pressure regulator system. Control is accomplished by means of a standard foot switch.

A reportedly unique feature of this machine is the sealed tubular construction of the upper arm, which provides a close-coupled surge tank, enabling unusually fast recovery of the air cylinder for consistent, rapid stroke action. Work thicknesses from 22 gage to $^1/_8$ in. are said to be efficiently handled.

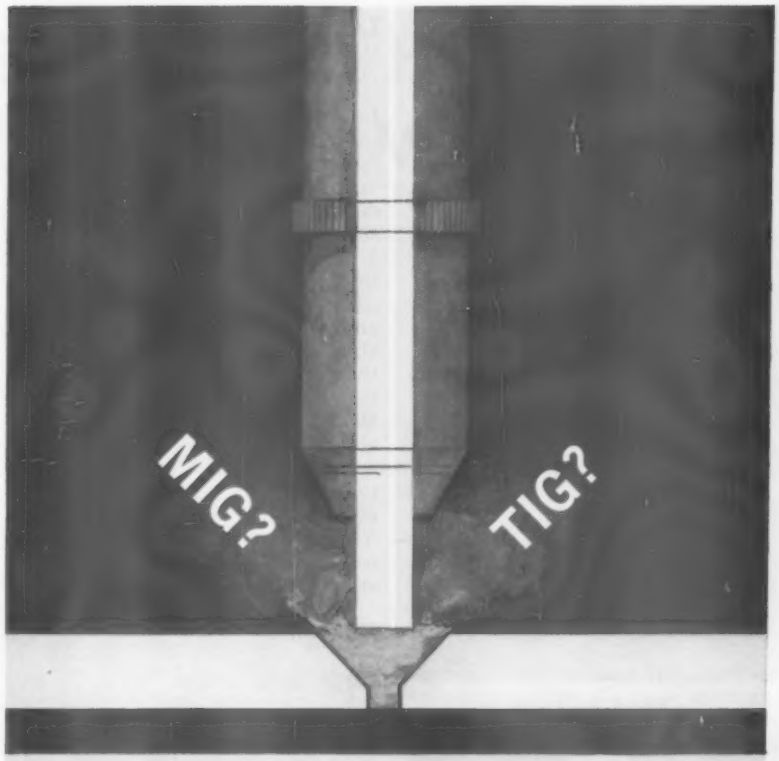
For details, circle No. 115 on Reader Information Card.

Miniature Welding Electrodes

A large selection of miniature welding electrodes, developed specifically for high-density electronic packaging, also used extensively in fabrication of miniature electronic components (diodes, transistors, resistors, receiving tubes, capacitors, etc.), are available from the Sippican Corp., Marion, Mass. Basic electrode size is $^1/_8$-in. diam x 2-in. long, available in 5 different tip configurations.

Tip diameters range from 0.025 to 0.090 in.

For details, circle No. 116 on Reader Information Card.



USE AMPCO-TRODE® 10!

Here's an ideal electrode and filler rod for inert-gas welding.

Available in spooled wire that feeds freely through MIG guns, or in easily handled 36" rods for TIG welding, Ampco-Trode joins copper alloys, iron, nickel-base and even dissimilar metals with strong, sound welds. Well-suited for fast buildup (160-190 Brinell), as well as fabrication and repair. Particularly adaptable where metal-to-metal wear or corrosion is encountered.

A companion electrode, Ampco-Trode 7, is also suited for MIG or TIG surfacing in corrosive situations such as tube sheet overlay, valve seats, bearing surfaces, salt water applications.

Your nearby Ampco distributor has both Ampco-Trode 10 and 7 in stock now. See him soon. Meanwhile, mail coupon below for more detailed information.

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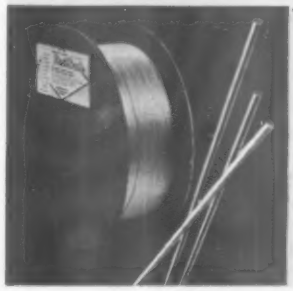

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HARD FACING PROBLEMS?
FIELD TESTS PROVE
WELDING TIME REDUCED
MORE THAN 50%
WITH MIR-O-COL M-700

The Semi-Automatic Open Arc wire feed unit is designed for the application of specially fabricated alloy wire by the open arc process. It operates on AC and DC or CV welders at 175-600 amperage range. Deposits 12-20 pounds of 7/64" wire in one hour at average 265 amp. Small, compact, weighs but 55 pounds.

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Hard Facing Alloys for Manual And Automatic Applications. Special Alloy Castings. Automatic Positioners And Welding heads.

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MIR-O-COL ALLOY CO., INC.

For details, circle No. 32 on Reader Information Card

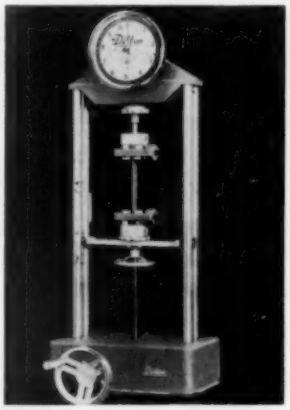
Thermal Protection Systems Materials Evaluator

The Thermal Dynamics Corp., Lebanon, N. H., has a standardized, calibrated, high-temperature materials testing apparatus for operation in the 30–200 kw power range, producing 10,000 mph gas streams with stagnation pressures ranging from 1 to 20 atmospheres. With this thermal materials tester, it is possible to measure heat conduction and resistance in thermal shock and ablation environments ranging from that seen by the leading edge of high Mach number planes like the B-70 to that encountered by a reentering missile nose cone like the Atlas. Emphasis has been placed on design of equipment which will give consistent reproducible results. The apparatus is calibrated prior to shipment against established standards.

For details, circle No. 117 on Reader Information Card.

Large-Sector Tester

Extra large sections of materials can be easily positioned and tested in a new Model LW extra wide tester made by Dillon & Co., Inc., Van Nuys, Calif. Standard width between the uprights has been increased approximately 80% from $8^3/_4$ to $14^1/_2$ in. In addition to this extra wide work area, four daylight openings are available (12, 20, 30, and 40 in.) to permit fixture travel



in excess of the greatest anticipated elongation.

These new Dillon instruments are made in seven capacities: 0–250, 0–500, 0–1000, 0–2500, 0–5000, 0–7500 and 0–10,000 lb. Tests of tensile, transverse, compression and shear can be made on materials with tensile strength varying from only a few pounds to as high as 400,000 psi.

For details, circle No. 118 on Reader Information Card.

Bench Welding Equipment

The latest SP.O Type Bench Welder (Model 369B) made by Sciaky Bros., Inc., 4915 W. 67th St., Chicago 38, Ill., is said to consistently weld small components and delicate parts of thin-gage material. Assemblies of nickel, tantalum, molybdenum, kovar, copperclad, etc., present no spot-welding problem. Its application ca-

pability has been proved in the fields of electronics, miniature devices and others. Machine speed can be adjusted to operator's capability.

Standard equipment includes a diaphragm head table mounted, a-c electrical and pneumatic controls, and welding transformer—available from 300 to 2000 va. These components may be bought separately. Bench top is 30 in. deep, 42 in. long and 32 in. from floor.

For details, circle No. 119 on Reader Information Card.

Plastic Flux Jars

Welding, brazing and soldering fluxes manufactured by All-State Welding Alloys Co., 249-55 Ferris Ave., White Plains, N. Y., are now packaged in unbreakable polyethylene plastic jars in $^1/_4$-, $^1/_2$- and 1-lb sizes.

The wide-mouthed plastic flux jars will be used for all but the most reactive fluxes. The wide-mouthed feature allows rapid flux dipping and application. Plastic jars are expected to eliminate shipping and on-the-job breakage and increase general sales appeal. Designed "low to the work bench," waste from spilled flux jars is expected to be reduced.

For details, circle No. 120 on Reader Information Card.

HOW TO SOLVE WEAR PROBLEMS *with CONFIDENCE*

Most problems of equipment wear are complicated by several wear factors, such as impact, abrasion, heat and corrosion. Choosing the best alloy for any set of conditions requires long experience plus an adequate selection of materials. Here's why STOODY, pioneers in hard-facing, gives you more for your hard-facing dollar and eliminates costly experimentation.

- **STOODY** is the only manufacturer that makes a complete line of hard-facing and build-up materials for manual, semi-automatic and fully automatic application.
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- **STOODY APPLICATION PROCEDURES** are the accumulative results of constant testing on the job. Proven procedures are carefully illustrated step by step and published for your use, making duplication easy.
- **STOODY** backs up its entire product line with over 40 year's specialization in the hard-facing industry. No other hard-facing manufacturer can offer equal experience.
- **STOODY** maintains a staff of qualified field engineers ready to help you solve wear problems on your own equipment in your own plant. Their knowledge is yours for the asking.
- **STOODY ALLOYS** are readily available everywhere. Over 750 STOODY dealers serve all parts of the United States as well as industrial centers of Canada and Mexico.

With *more* hard-facing alloys, *more years* of experience, *ready product availability* in all locations and a working staff of *trained field engineers* covering the nation, STOODY serves *all* your hard-facing needs faster, more specifically and with greater satisfaction.

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STOODY 104	STOODY 121
STOODY 105	STOODY 130
STOODY 106	STOODY 134

STOODY NICKEL MANGANESE

MANUAL RODS AND ELECTRODES

STOODY BUILD-UP	TUBE STOODITE
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STOODY 2110	STOODY 2134
STOODY 1105	STOODY 6
STOODY 1027	STOODY 1
STOODY SELF-HARDENING	BOROD
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NOZZLE HOLDERS AND PARTS

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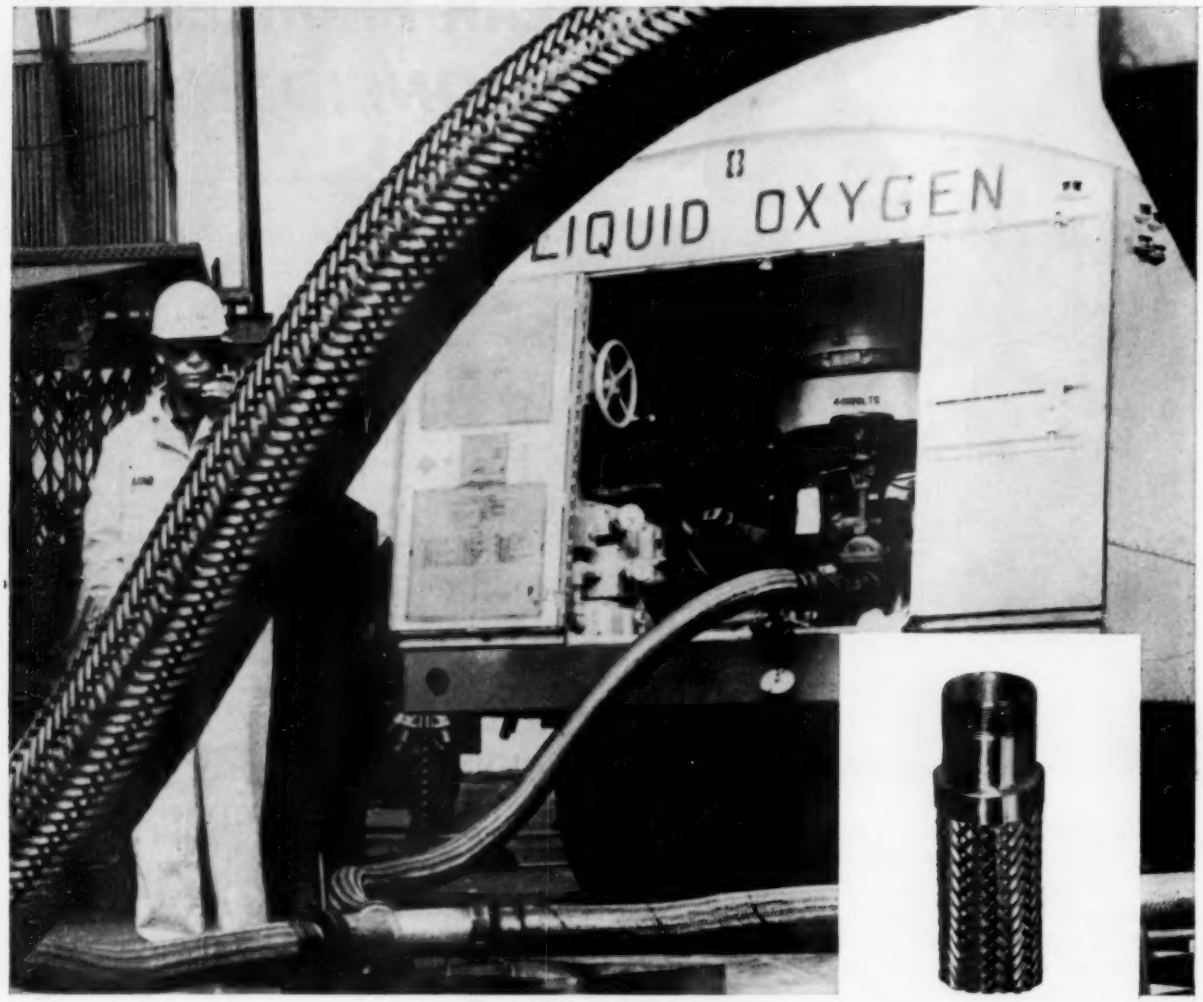
Call your Stoody Dealer (check the yellow pages of your phone book). He will arrange for a visit from your nearest Stoody Field Engineer—or write to the factory.

STOODY COMPANY

11986 East Slauson Avenue
Whittier, California

For details, circle No. 33 on Reader Information Card

3½ inch I.D. Anaconda flexible metal hose lines are shown here transferring liquid oxygen to Army missile. Brazed metal hose-to-fitting connections are made with Handy & Harman brazing alloys.



Handy & Harman Brazed Connections Withstand Thermal Shock From Liquid Oxygen . . . Time After Time

It is hard to think of a single more punishing test for a metal joint than the nearly instantaneous plunge from approximately 100° F to —297.4° F experienced by these brazed metal hose connections. Yet they take it time and again — and come back for more.

This is part of an assembly employing Type 321 stainless steel flexible hose made by Anaconda Metal Hose to transfer liquid oxygen to Jupiter missiles at the Redstone Arsenal. Fittings are stainless steel, integrally bonded to the hose by Handy & Harman brazing alloys — EASY-FLO and EASY-FLO 35 with Handy Flux. The reasons for using Handy & Harman brazing alloys here make good fabricating sense no matter what the job. First, they provide strong, integral joints that remain strong, ductile and resistant to vibration and shock even to liquid oxygen temperatures and pressures where many metals become brittle. Secondly, they allowed Anaconda to increase burst pressure limits since there is no annealing of the base metal. In addition, they make it possible for Anaconda to perform joining operations with less equipment and less expense in manpower than would otherwise be necessary.

This is only one example of many applications of Handy & Harman brazing products in cryogenics and other fields of engineering to solve critical bonding problems which achieve fast production and operating economies. There's a good chance they will do the same for you. Call or write for further information on how to apply brazing techniques to solve your fabricating problems.

Our Bulletin 20 contains a wealth of data on silver brazing, its range of applications and techniques for securing best results. Write today for your copy.

Your No. 1 Source of Supply and Authority on Precious Metal Alloys

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Welding Research

Sponsored by the Welding Research Council of the Engineering Foundation

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SUPPLEMENT TO THE WELDING JOURNAL, JUNE 1961

Welding of An Ultra High Strength Steel for Missile Motor Cases

Following full heat treatment, satisfactory gas tungsten-arc welds are made in 0.080-in. thick 300M steel without cracking difficulties

BY J. F. RUDY, J. I. FISHER, J. P. SHEEHAN, F. SUYAMA AND H. SCHWARTZBART

SUMMARY. This paper reports the results of recent studies of the problems associated with the fabrication of 300M steel for solid propellant rocket motor case application. Specimens of several geometries were joined for this study with gas tungsten-arc welding. The welding procedural details are presented and discussed. The behavior of weld joints was evaluated after heat treatment in various ways under uniaxial loading, both transverse and parallel to the direction of welding, and under biaxial loading.

The three loading systems provided an evaluation of the mechanical behavior of the weldment specimens after standard heat treatments and after various special treatments including minor heat-treatment variations, surface decarburization and cold rolling. It was possible to find treatments which appreciably enhanced the ability of the specimens to strain prior to fracture—particularly those specimens containing flaws—while maintaining satisfactory engineering strengths.

Introduction

Solid propellant missiles have created an immediate demand for ultrahigh-strength, low-weight pressure vessel materials. Several alloy types have been given consideration as possibilities for filling this demand, among which are the newer titanium alloys, hot die tool steels, precipitation-hardening stainless steels and low-alloy high-strength steels. The subject alloy, 300M, is a representative of the latter class.

The research efforts from which the data for this paper were taken were directed primarily toward the missile motor case problem. The studies were essentially weldability experiments—"weldability" herein defined in the broad sense to include, in addition to the factors which can be directly associated with the mechanics of performing the weld, those related mechanical and thermal fabrication variables which are important in determining the final properties of the composite specimen.

The low-alloy, high-strength steels develop their strengths by a quench-and-temper heat-treatment cycle. The 300M alloy is essentially a high-silicon 4340. The higher silicon content serves to increase the optimum tempering temperature, for high strengths, to 600° F, a temperature which would cause temper embrittlement in 4340. The background for the development of this alloy has been discussed in the literature.* The alloy is designed for the ultimate strength level of 280 to 300 ksi with a yield strength (0.2% offset) of approximately 230 ksi.

Welding Procedure and Parameters

Procedural Details

The welding procedures which were found most satisfactory for this alloy are basically in conformance with good gas tungsten-arc welding practice. The secret of performing successful weldments is simply to exercise every imaginable precaution to obtain clean, dense welds with satisfactory geometry. This emphasis on carefulness is particularly important for the motor case application.

The details of the welding procedure are as follows. The welds were deposited manually because better results (fewer flaws) were obtained than with automatic movement of the electrode and filler wire. The tungsten electrodes were the standard 1% thoriated type; the torch and gas cup were also standard commercial equipment. Electrode shape and cleanliness are important aspects of the above-mentioned emphasis upon procedural care. It was the welder's practice to prepare 4 to 6 tungsten wires at one time

J. F. RUDY, J. I. FISHER, J. P. SHEEHAN, F. SUYAMA and H. SCHWARTZBART are with the Metals Div., Armour Research Foundation, Illinois Institute of Technology, Chicago, Ill.

Paper presented at AWS 41st Annual Meeting in Los Angeles, Calif., Apr. 25–29, 1960.

* "300M Ultra High Strength Steel," The International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.

so that they could be conveniently exchanged as soon as the electrode became contaminated or misshapen. The electrode, $^1/_{16}$ in. diam, was prepared by hand grinding to a 15 deg included angle pencil point. The sharp tip was removed to more closely approximate the natural rounding which occurs after a short time of arcing.

The shielding gas on the torch side of the weld bead was argon, fed at 8 cfh through a $^5/_{16}$-in. ID cup nozzle. The underside of the weld bead was also shielded with an inert gas, ordinarily helium (approximately 2 psi or 5 cfh). The means for introducing this backside coverage was such that the inert gas provided the support for the welding puddle. This differs from the practice of supporting the bead directly with a copper chill bar. The rapid quench obtained with direct contact to the chill bar has been associated with weld-metal cracking.

The design of inert-gas pressure support for the underside of the weld bead assumes different forms, depending upon the geometry of the specimen. The plane sheet butt joints (for uniaxial tension and biaxial bulge testing) were made in a jig as shown in Fig. 1. This jig incorporates a conventional copper backing bar, but the bar is grooved to a depth which is sufficient to prevent the liquid metal from making direct contact with the copper. Instead, the liquid metal sags slightly but is partially supported by the inert-gas pressure within the groove, resulting in a slightly convex underside contour with a bead build-up of approximately 0.015 in.

For small pressure vessel specimens, the underside inert-gas pressure was maintained within the whole vessel rather than just within the backing groove. With this technique, it is important to prevent underside pressure buildup which may occur as the gas leak paths are closed by the progressing weld bead. This can be accomplished by providing additional leak paths so that, even when the girth weld is completed, the gas leakage is still sufficient to prevent excessive pressure build-up. (The consequence of excessive underside pressure is either the rupture of the liquid metal bridge or the introduction of inert gas to the puddle and resultant porosity.) Vessels were rotated during welding with a positioner, but the welding was again manual.

Several welding filler metal compositions were evaluated during the course of the study. The wires were manually fed and were approximately $^1/_{16}$ in. diam. The filler wires were cleaned by abrasion with emery cloth just prior to welding. The amount of filler wire used depended upon the joint design, but it was always just sufficient to provide a slight build-up on both the top and bottom of the weld. Care was taken to keep the hot end of the filler wire within the protective inert-gas shield during welding.

Several sheet thicknesses were included in the program. Although the range was not wide (0.080 to 0.125 in.), joint design modifications were found necessary to obtain optimum weld quality. The 0.080-in. material, with which the bulk of the experimental effort was performed, was welded in a straight butt configuration as shown in Fig. 2. Preparation for this joint consisted of abrasive cleaning of the faying and adjacent surfaces, and of taking care to obtain straight edges so that the gap could be maintained as uniformly close to zero as possible over the weld length. The arc heat was sufficient to cause complete penetration of the seam with the single weld pass, adding just enough filler metal to obtain slight fall-through (underside build-up) and slight topside build-up. Occasionally a second "clean-up" pass was made to repair any surface irregularities, such as slight undercut or incomplete penetration, which may have appeared. However, the weld was designed as a single pass.

The straight butt joint with no gap was satisfactory for all welds in 0.080-in. sheet. However, the relatively minor increase in thickness to 0.093-in. sheet introduced weld-metal porosity difficulties. In order to eliminate porosity the general solution was to control solidification front geometry and solidification speed. This is explained with the aid of Fig. 2, which illustrates two typical possibilities. On the top sketch the weld puddle has less weld metal and, therefore, freezes faster. It also has a more

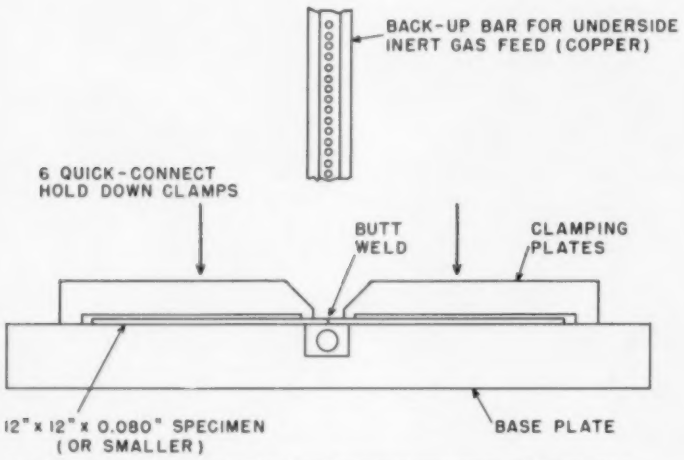


Fig. 1—Clamping and underside inert-gas feed arrangement for welding

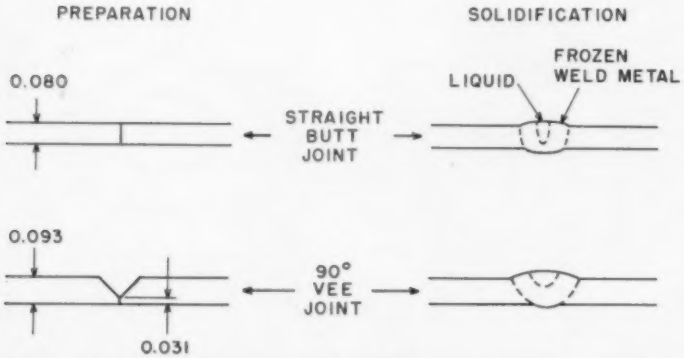


Fig. 2—Joint designs and corresponding solidification geometry. The dish-shaped solidification with the vee joint captured fewer pores

vertical solidification front. These two factors assist the capture of any gas which may be rejected by the advancing solidification front. The lower schematic is a more advantageous solidification picture for floating the gas.

Thus the porosity was alleviated by changing to a vee preparation. This gave satisfactory results until the thickness was increased to 0.125 in. The solidification pattern was further adjusted for this thickness by providing a less penetrating heat input—i.e., shallow heat input was provided which widened the top surface of the puddle and allowed it to solidify even slower. This shallower heat input pattern was obtained by switching from a direct-current, straight-polarity arc to the less penetrating alternating current arc. This particular procedural change was successful, but it is probable that other means of obtaining the same modified heat pattern (e.g., longer arc, weaving arc path, or slower travel speed) would accomplish the same result.

A study to evaluate the effects of material cleanliness, heat input and arc penetration on the incidence of porosity generally indicated that a narrow, high-speed weld bead captured appreciably more gas, causing porosity, than a normal width bead. When the narrow bead was welded with scaled filler wire (as opposed to abraded wire), the porosity was even more prevalent. The presence of scale on the wire, with normal width beads, however, did not cause porosity in the few specimens which were made for the purposes of this experiment.

Preheating

In determining the welding procedure for a steel of this ultrahigh-strength level, preheat is always one of the techniques to be considered for avoiding difficulty. Aside from hydrogen embrittlement considerations, which are not applicable with the gas tungsten-arc welding process, preheating is useful primarily as a means of altering transformation products (and the residual stresses resulting from the transformations) during the cooling of the austenitized portions of the weld area. With steels of low hardenability, the difference in cooling rate resulting from preheat can result in the prevention—or marked reduction in the amount—of low-temperature transformation products such as lower bainite or martensite. However, the time-temperature-transformation curve of this alloy in Fig. 3 shows this to be impractical in this case since the high-temperature transformations (1200° F) require on the order of 2×10^4 sec (about 6 hr), to reach completion. Reasonable preheats (300–400° F) would be expected to assist in the prevention of cracking only by modifying the rate of martensite formation and, therefore, moderate the residual stresses set up by this transformation and by changing the relative amounts of lower bainite and martensite. Preheats higher than these may offer the advantage of almost complete transformation to lower bainite (no martensite) if held for 30 min after welding, but these higher temperatures (−600° F) cause practical welding difficulties—i.e., welder discomfort and increased porosity, the latter probably caused by scaling of the base-metal surfaces during preheating.

Preheat was studied as a welding parameter in a series of transverse tensile weld specimens cut from 6- x 6-in. sheets which were welded at various temperatures between 400 and 900° F. The resulting tensile properties of these welds, after heat treatment, are plotted in Fig. 4. The strength and elongation values of specimens welded at room temperature are not significantly different from the 400° F values, and the higher preheat temperatures apparently cause a decrease in elongation. Therefore, preheat was not justified on the basis of improved performance in this test. The one joint which was regularly preheated was one in which the restraint was particularly high. This was a $2^1/_2$-in. diam circular weld which joined a pressure fitting boss into the pressure vessels. The problem which necessitated preheating was the high incidence of weld bead cracking. However, even with the 600° F preheat procedure, repairs in this weld were required with appreciably greater frequency than with room

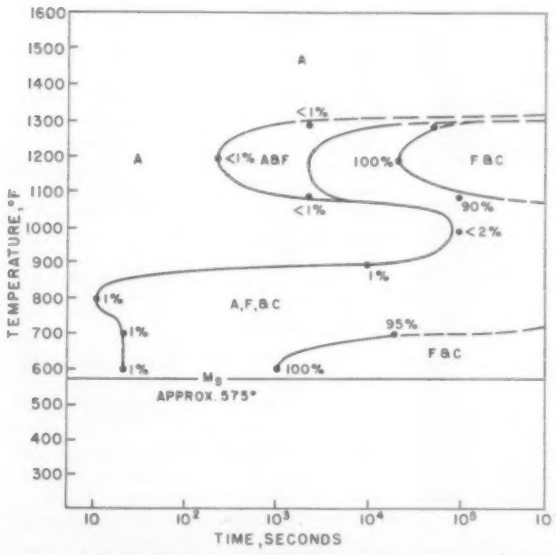


Fig. 3—Time-temperature-transformation plots for 300 M

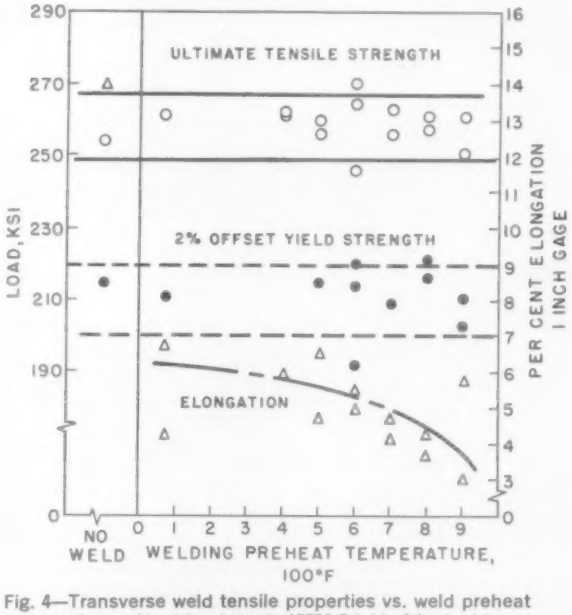


Fig. 4—Transverse weld tensile properties vs. weld preheat temperature. Heat treatment: 1575° F (air), OQ, double temper 600° F, 1 hr each.

Fig. 5—Typical weld bead cracking obtained with Heat No. 03690 (Table 1) filler wire

temperature plane or girth butt welds. Therefore, it cannot be ascertained that preheat was effective in alleviating the cracking problem.

Cracking—Filler Wire Composition

Weld area cracking was not a major problem with joint designs other than the circular pressure-fitting configuration mentioned immediately above. Generally, cracks occurred only at starting or stopping points where no effort was made to avoid them, since tabs were used. However, one particular filler wire did give cracking trouble. The analyses of this wire is given in Table 1 along with an analysis of a more successful filler wire and of the base metal for comparison. The crack-susceptible heat had relatively high sulfur (0.022%) which probably contributed to this difficulty by a hot-short mechanism. The cracking problem was increased, with this wire, by a wide bead welding technique. An example of the cracks which were experienced is shown in Fig. 5.

Table 1—Composition of 300M

Heat No.	Weight, % C	Mn	P	S	Si	Ni	Cr	V	Mo	Al
Specified (min.)	0.40	0.65			1.45	1.65	0.70	0.05	0.30	0.07
Range (max.)	0.47	0.90	0.025	0.025	1.80	2.00	0.95		0.45	
03653 (0.080-in. sheet)	0.40	0.78	...	...	1.65	1.94	0.79	0.09	0.42	...
03690[a] (0.063-in. wire)	0.43	0.98	0.01	0.022	1.79	1.77	0.82	0.09	0.40	...
03532 (0.054-in. wire)	0.40	0.84	0.012	0.015	1.51	1.85	0.84	0.08	0.38	0.07

[a] This filler wire gave weld-metal cracking difficulties—see Fig. 5.

Quality Control

Since the programs which contributed to this paper were directed toward determining the optimum mechanical properties which can be expected and assuming weld quality to be as high as can possibly be obtained, all test welds were X-rayed (and repaired, when the need was indicated) prior to testing. During the course of the programs, it was found that moderate porosity could sometimes be tolerated without appreciably modifying mechanical properties. By moderate porosity is meant that no pores greater than approximately $^1/_{32}$ in. in diam were tolerated, and these pores could occur no more frequently than 2 or 3 per ft of weld. Welds with lesser degrees of porosity than this were tested, and the results were often comparable to other specimens which were radiographically perfect. The area of any flaw indication, which suggested a crack or a nonfusion area, was repaired by grinding and rewelding.

Later inspection of fracture surface, as discussed in the data section of the paper, suggests that flaw size is not as important as the position of the flaw. Pores which occur close to a surface can cause premature failure, while larger centerline flaws may have little or no effect. Since flaw depth in thin sheets is difficult to determine radiographically, almost any indication may be suspect unless material properties are adjusted to allow for the flaw.

Discussion—Mechanical Properties

The order of presentation of results will be to itemize the properties which were obtained with what is essentially "normal good heat-treatment practice", then to cover the deleterious effects of particular deviations from this practice, and finally to present the improvements in weldment properties which can be obtained with special mechanical and/or thermal treatments. Heat treatments referred to were performed after welding in all cases.

Standard Heat Treatment

The material was received in the spheroidize - annealed condition. This annealing treatment consisted of equilibrating at 1450° F, cooling at 10° F per hr to 1200° F, further

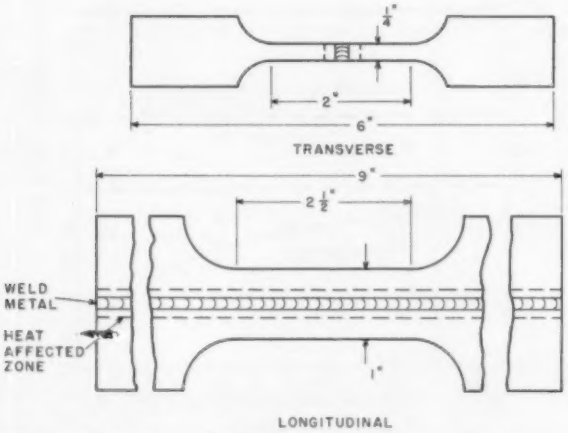
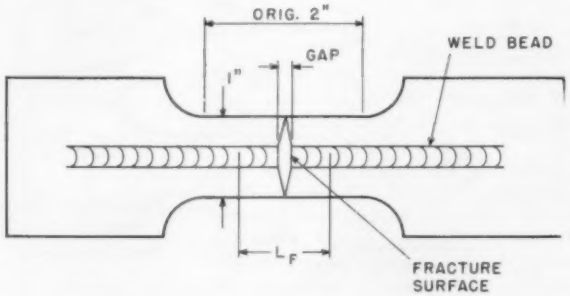


Fig. 6—Weld tensile tests showing specimen dimensions for the transverse and longitudinal orientations



$$\text{BASE METAL ELONGATION PER CENT} = \frac{L_F - L_0}{L_0} \times 100$$

$$\text{WELD METAL ELONGATION PER CENT} = \frac{L_F - \text{GAP} - L_0}{L_0} \times 100$$

Fig. 7—Schematic method of measuring base-metal and weld-metal elongation in a longitudinal weld tensile specimen. L_0 (original) was 1 in.

cooling at 20° F per hr to 900° F, and air cooling. In this condition the material has a hardness of 17 to 23 R_c and is quite formable.

The weld was made with the sheet in this condition. If no post-weld forming was required, the welded specimen was then heat treated. If forming was required (as with all biaxial bulge test specimens) or if any appreciable handling was foreseen, the weldment was spheroidize-annealed (and formed) prior to heat treating.

The recommended heat treatment consisted of normalizing at 1700° F, furnace cooling to 1600° F, and air quenching. This was followed by a double temper at 600° F for 2 hr each. Variations in number of tempering cycles and in time per cycle had no practical effect on results, but double tempering is considered to be advisable.

All thermal treatments which exceeded approximately 1200° F were conducted in an argon atmosphere to prevent decarburization.

The mechanical properties of welded specimens which had been heat treated as outlined are reported below for various specimen loading systems.

Uniaxial Tension, Weld Transverse. The standard specimen for this test is shown in Fig. 6. Typical results are summarized in Table 2. The weld specimens (the numbers entered are the average of 9 weld specimens) show very attractive properties. The joint efficiency, based on yield point, is approximately 96%, and the 6.5% elongation is comparable to the parent metal figure.

The typical failure location was consistently at the low-temperature extreme of the heat-affected zone (HAZ), as defined by change in metallurgical structure. This is approximately $^1/_{10}$ to $^1/_8$ in. from the fusion line. No clear explanation of this fracture location preference is apparent. It indicates that the base metal or the low-temperature HAZ has a lower yield point and is able to elongate prior to fracture.

Uniaxial Tension, Weld Longitudinal. The transverse weld tension test loads each zone of the composite specimen to the same *stress* (assuming a uniform specimen cross section). The strain experienced by each particular zone is, to the first approximation, dependent upon its inherent stress-strain behavior, and thus the zone strain will probably not be uniform. Since the ability of the composite specimen to strain is also of en-

Table 2—Tensile Properties of 300M (Standard Heat Treatment[a])

	Ultimate tensile strength, ksi	Yield strength (0.2% offset), ksi	Elongation (1-in. gage), %	Location of fracture
Parent metal				
Max	301	262	5	...
Min	259	232	8	...
Avg	280	247	6.5	...
Weld specimens[b]	273	237	6.5	Low-temperature extreme of HAZ

[a] 1700° F, $^1/_2$ hr; FC to 1575° F, $^1/_2$ hr (argon) → OQ; double temper 600° F, 1 hr each.
[b] Weld direction transverse to loading.

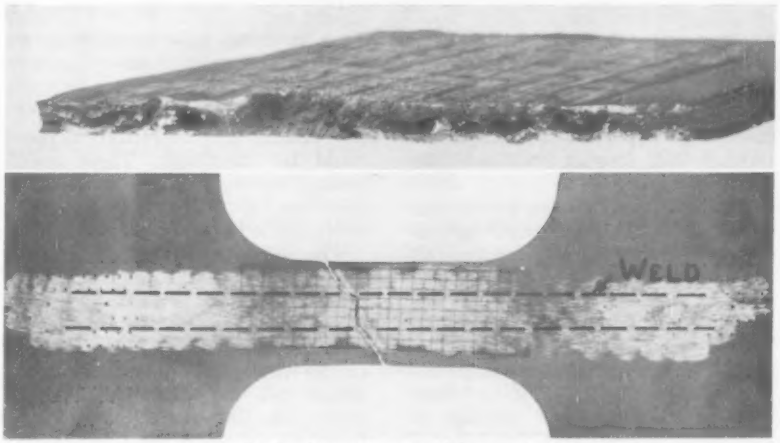


Fig. 8—Fracture of a longitudinal weld specimen which contained no flaws. The elongation is fairly uniform over all the weld zones and the fracture texture is shear

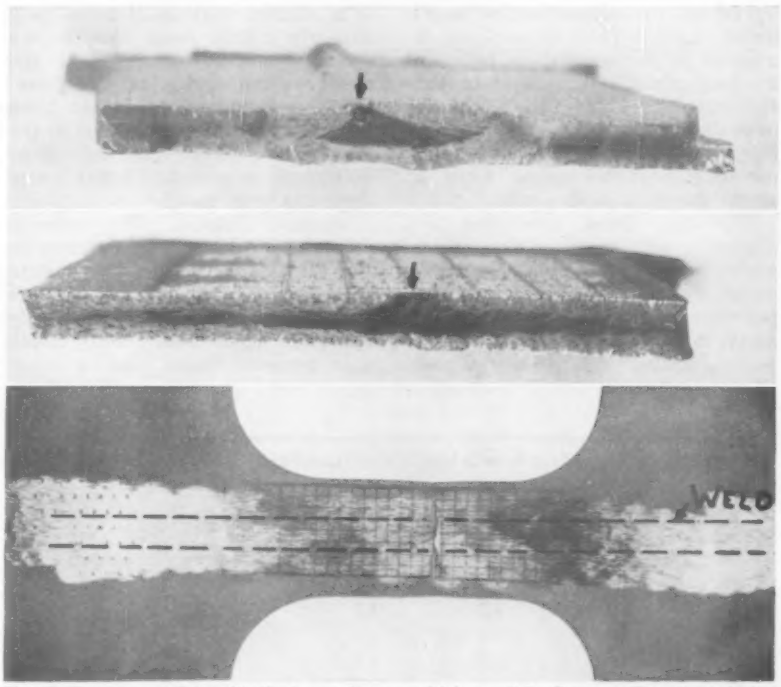


Fig. 9—Fractures of longitudinal specimens which contain flaws. The top photograph shows a fracture surface which contained a pore. The bottom photographs show a fracture with a small surface flaw as indicated. (The brittle portions of the surfaces were shadowed and thus appear dark)

Table 3—Tensile Properties of 300M, Weld Direction Parallel to Loading (Standard Heat Treatment)

Weld No.	Ultimate tensile strength, ksi	Elongation, % (1 in. gage) Base metal	Weld metal	Apparent initiation of fracture
153A	253	7	6	No flaw
153B	259	8	7	No flaw
153C	264	8	6	No flaw
65	264	6½	2	Minute WM surface flaw[a]
67	268	4	0	Minute WM surface flaw
81	268	5	1	0.038-in. WM pore[b]
83	268	5	1	0.028-in. WM pore
Avg	263	..	..	...

[a] These flaws penetrated approximately 0.002 to 0.004 in. and had the discolored appearance of a hot crack.
[b] These pores were not open to the surface, but they were within a few thousandths of the surface.

gineering importance, the longitudinal weld tension specimen provides valuable supplementary data.

The specimen for this test is also shown in Fig. 6. The gage length is sufficiently wide (1 in.) to include all the weld zones from base metal to weld metal to base metal. The results of the longitudinal tension testing are given in Table 3. The strengths were generally within the range to be expected of the base metal, although their average is somewhat lower. The analysis of the elongation behavior, which was the primary purpose of testing with this orientation, shows that there is a marked dependence of strain behavior on the occurrence of weld-metal flaws. This dependence is evident in the correlation between the weld-metal elongation data and the remarks concerning fracture initiation. (The procedure for obtaining both base-metal and weld-metal elongation values from a single specimen is shown in Fig. 7.)

The first three specimens exhibited weld-metal elongations which were comparable to the base-metal values. Their fracture appearance is typified by the photograph in Fig. 8. The whole surface was "ductile," i.e., 45-deg planes of fracture, and no initiation point could be identified. These specimens illustrate the ideal, or no-flaw, behavior of the weld metal and heat-affected zone.

The next four specimens gave little or no plastic deformation in the weld metal prior to fracture. These specimens all contained small weld-metal flaws—either surface cracks which were not visible to the naked eye or small pores which were close to the surface. Typical fractures of specimens containing flaws are shown in Fig. 9. (In these photographs the "brittle" portion of the fracture surfaces was shadowed and appears dark.) Thus it is evident that small flaws, particularly if they occur close to the specimen surface, severely limit the ability of the weld metal to deform. These small flaws would not have been shown to be deleterious in the transverse weld specimen since those specimens repeatedly failed away from the weld metal.

Biaxial Tension. The uniaxial tension tests described previously do not duplicate the loading system of a thin-walled cylindrical pressure vessel or missile case. The only specimen which does exactly duplicate pressure vessel loading is, of course, an actual pressure vessel. However, in the interests of obtaining a degree of economy which would allow appreciable numbers of specimens to be tested in a reasonable length of time, the biaxial bulge test was adopted. The details of this test are outlined in the appendix.

The loading with this test is in the ratio 1:1. Weld specimens were designed such that the weld itself was in the 1:1 portion of the specimen, i.e., the load was equal in all directions as in a balloon. The specimen is a 12-in. circle with a diametrical weld joint. The test area is a 7-in. circle, and the biaxial area of maximum loading is approximately a 2-in. circle. Table 4 gives results obtained with this test with normal heat treatment. The strength figures are generally satisfactory, but the total strain figures are somewhat low, particularly on specimens 363 and 59. A direct comparison of these data with the percent elongation reported for the uniaxial tests is not justified, since the elongations of the latter tests include the appreciable nonuniform plastic strain which occurs during necking. The biaxial specimen, on the other hand, strains uniformly until rupture, which occurs with essentially no necking. However, the total strain figures should be an indication of the amount of uniform strain which can be expected during service and may, therefore, be a better measure of service behavior. It is of interest to note that the theoretical degree of uniform strain which is predicted with this specimen is in excess of 20%, owing to the greater stability with the biaxial loading system. Therefore, it can be concluded from these data that the biaxially loaded specimens which were tested did not behave as a homogeneous piece of material (not a surprising conclusion in the light of prior uniaxial test results) and that this deviation in behavior results in uncomfortably low uniform elongations (total strains).

The fracture paths of the biaxial specimens were not as consistent as with the two types of uniaxial tension specimens. Some specimens failed perpendicular to the weld bead similar to the uniaxial longitudinal specimen. In these cases the fracture often appeared to initiate at a weld bead flaw, as with the longitudinal uniaxial specimen. Another frequent fracture path was parallel to the weld bead. The location of this fracture was not confined to the cold extreme of the heat-affected zone, as with the trans-

Table 4—Biaxial Bulge Test Results with Diametrical Welds (Standard Heat Treatment)

Specimen No.	Ultimate tensile strength, ksi	Yield strength (0.2% offset), ksi	Total strain, %	Fracture comments
361	283	249	2.2	...
362	275	237	3.2	...
363	221	221	1.1	...
365	264	232	3.0	...
58	257	213	3.4	Irregular inclusion (0.040 × 0.014)
59	238	234	1.2	Grinding scratch
Avg	258	231	2.3	...

verse uniaxial specimen, but was liable to occur at any zone over the whole weld-affected area. A careful study of the parallel fractures suggested that the predominant initiation point of fractures in this direction is some form of surface irregularity. The most common irregularities were (1) the change in cross section at the edge of the weld bead and (2) the grinding scratches which were left after the bead was removed. (Biaxial specimens were tested both with the weld bead left on and after grinding the bead flush.)

There were some fractures which could not be attributed to surface irregularity and which initiated in the weld metal, usually at a pore. Thus it seems likely that the primary causes for low total strain figures with the bulge test are (1) surface irregularities, or (2) weld-metal flaws. (The critical flaws are on the surface in most cases.) Once this viewpoint is adopted, the fractures of the biaxial test appear to tell the same story as the longitudinal uniaxial tension test—i.e., that the material is able to elongate to a considerable extent unless the presence of a surface flaw causes premature failure. Even the no-flaw specimens, however, fail with lower elongations than the homogeneous base metal. The biaxial test did point out the importance of surface irregularities which run parallel to the bead, a flaw geometry which was not critical with the uniaxial longitudinal tension test.

Table 5—Typical Reduced Strengths Resulting from Heat-treatment Variations

Heat treatment	Ultimate tensile strength, ksi	Yield strength (0.2% offset), ksi	Elongation (1-in. gage), %
1700° F, 1/2 hr, FC→1600° F, 1/2 hr (argon)→AC; 600° F temper (proper ht. tr.)	280	247	6 1/2
Same as above except for air rather than argon atmosphere in furnace (excessive decarburization)	228	192	9
1575° F, 1 hr (air)→OQ; 600° F temper (failure to normalize prior to quench)	254	215	14

Deleterious Variations in Heat-treatment Procedure

The foregoing has been a summation of the mechanical properties that can be expected with the standard heat treatment as recommended by the International Nickel Co. Before going into a discussion of special modifications which were found to offer property advantages, it may be well to review some of the undesirable deviations which were experienced.

Excessive Decarburization. Early heat-treatment batches were austenitized in air rather than argon or a comparable neutral atmosphere. The resulting specimens (uniaxial tension, no weld) were low in strength, as shown in Table 5. The cause of this reduction was loss of carbon to an appreciable depth.

Omission of Normalization Prior to Quench. A second heat-treatment deviation was to omit the excursion to 1700° F prior to the air quench from 1575–1600° F. The purpose of the high-temperature normalization is to insure solution of alloy carbides which may have formed. Failure to perform this "re-solution" ties up some of the alloy and carbon atoms which would otherwise be available as solution

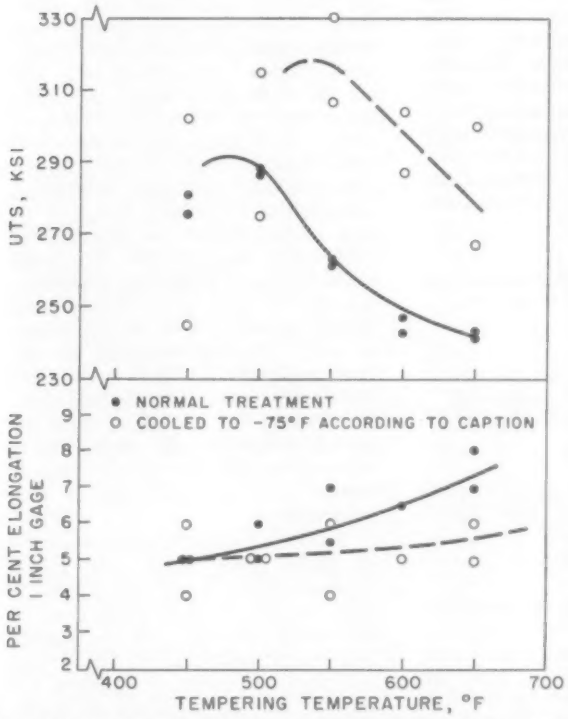


Fig. 10—Tensile properties vs. tempering temperature. Heat treatments: 1700° F 1/2 hr, FC to 1600° F, hold 1/2 hr (argon), OQ, cool to −75° F as indicated. Double temper (cooling between tempers as indicated) at T° F, 2 hr each temper

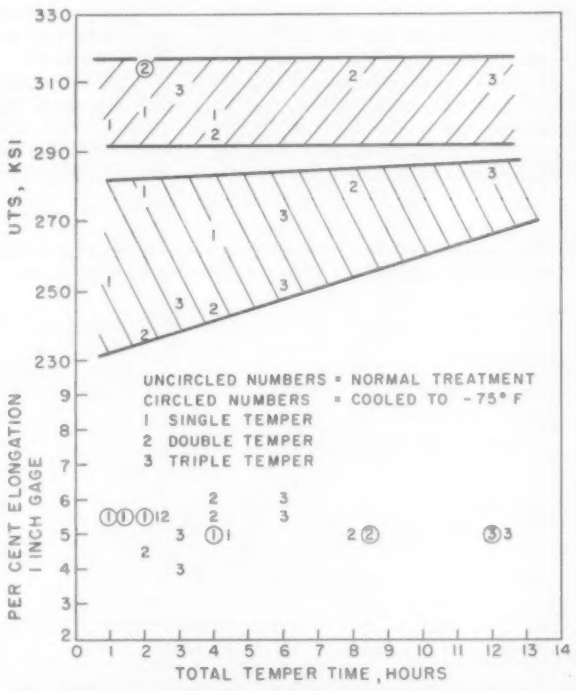


Fig. 11—Tensile properties vs. total tempering time. Heat treatment: 1700° F, 1/2 hr, FC to 1600° F (argon) hold 1/2 hr, OQ, cool to −75° F as indicated, temper at 600° F as indicated

Table 6—Calculation Composition of Weld Beads Made with Lower Alloy Filler Wires

Filler wire	Gap,[a] in.	Analysis, weight %: C	Mn	Si	Ni	Cr
300M	...	0.40	0.77	1.62	1.82	0.83
Mild steel	0.020	0.38	0.73	1.43	1.61	0.73
Mild steel	0.040	0.36	0.71	1.29	1.46	0.66
4320	0.020	0.38	0.75	1.48	1.82	0.80
4320	0.040	0.36	0.73	1.35	1.82	0.76
4320	0.080	0.33	0.69	1.12	1.82	0.71

[a] Straight butt joints with indicated gap.

additions to the matrix. The practical result is a decrease of the heat-treated strength as shown by the final entry of Table 5.

Special Techniques to Enhance Properties

Higher Strength Heat Treatments. A program was conducted to determine the effects of various tempering cycles on strength. The two means chosen to increase strength were to reduce the tempering temperature or to chill the specimens prior to each temper cycle. The results of both factors are summarized in Fig. 10. (These specimens did not contain welds.) The most consistent indication is the increase in strength, with only nominal sacrifice in tensile elongation, which was obtained by cooling to −75° F after each air cooled to room temperature. The increase in strength with decreasing tempering temperature is also shown. The highest strengths were obtained with a double temper at 550° F in combination with the refrigeration treatments. This treatment gave an ultimate tensile strength of approximately 315 ksi with 5% elongation in 2 in.

An experiment was also conducted to determine the effect of the number of temper cycles, i.e., single, double or triple temper, on the properties of the base metal. These tensile property data are plotted vs. total tempering time at 600° F in Fig. 11. With refrigeration treatments the properties appear to be independent of both parameters, i.e., number of tempers and total tempering time. The properties of room-temperature-cooled specimens (normal procedure) also appear to be independent of the number of tempering cycles (the double-tempered specimens average lower strength than both the single and triple tempers). However, there is an indicated tendency for higher strengths with longer total tempering times. This conclusion is of marginal validity, however, and it appears that the tempering and quenching temperatures are the most important parameters.

Treatments to Increase Ductility. The discussion of behavior under the various systems of loading with the standard heat treatment suggested that a flawless, welded specimen exhibited satisfactory ductility prior to fracture. However, those specimens which contained flaws, particularly flaws which were on or near the surface, exhibited much higher strain sensitivity when the loading system was such as to impose straining of the flawed area. The end result of this strain sensitivity was scatter of the strain data, depending upon the chance occurrence of weld-metal or specimen surface flaws. Thus a considerable experimental effort was directed toward developing treatments which would render the composite specimen better able to compensate for the presence of these flaws.

Lower Alloy Weld Metal. The critical zone for low-strain fractures appears to be the weld metal itself, particularly in the presence of minute flaws which are more likely to occur there than elsewhere. Thus a logical goal was to obtain a weld metal which was better able to strain in the presence of flaws. The transverse tension test results have shown that 300M weld metal has at least slightly greater strength than the other zones of the specimen. Therefore, the following experiments were performed to study the behavior of composite specimens which had softer weld metals. Four different filler alloys were chosen, and the joint design was altered to allow for various degrees of base metal-filler metal mixing. Two of the four alloys, 6434 and 4340, were not sufficiently different from 300M to provide appreciable chemistry change. Therefore, only the results with mild steel and 4320 wires will be discussed. Table 6 gives the calculated weld-metal compositions with 0.020-, 0.040- and 0.080-in. weld joint root gaps, assuming a reasonable amount of base metal (300M) contribution for each joint design. The compositions obtained with this technique are not so radically different from 300M as would first be imagined. In fact, with the exception of carbon and silicon, the weld-metal compositions are generally still within the accepted allowable range for 300M. Carbon and silicon were reduced to 0.33 to 1.12%, respectively, with the wide gap (1 x t) joint design.

The longitudinal tensile properties of these lower alloy weld metal specimens are given in Table 7. The strengths remain fairly close to the levels obtained with the control specimens with 300M filler wire, and the weld-metal elongations are considerably higher than the specimens of Table 3. However, there appear to be fewer flaws in these specimens (Table 7) which may account for the strain improvement;

Table 7—Longitudinal-weld Tensile Properties with Lower Alloy Filler Wires

Specimen No.	Wire	Butt joint gap, in.	Ultimate tensile strength, ksi	Yield strength (0.2% offset), ksi	Elongation, % (1-in. gage): Base metal	Weld metal	Flaws observed in weld metal fracture surface
54	300M	0	264	225	7	6	None
58	300M	0	251	211	12	11	None
60	300M	0	241	216	8	4	Two 0.020 in. pores near center of specimen
74	Mild steel	0	264	212	10	9	None
76	Mild steel	0.040	252	225	8	4	0.006 in. pore near surface
64	4320	0	258	225	10	9	None
66	4320	0.020	258	222	10	9	0.010 in. pore near center of specimen
68	4320	0.040	240	208	9	8	None
70a	4320	0.080	240	227	9	9	None
70b	4320	0.080	242	211	8	2	0.015 in. pore, 0.010 in. from surface

but there is one specimen from each category which did have a flaw on its fracture surface.

The 300M filler wire specimen with two 0.20-in. diam pores gave a creditable 4% elongation in the weld metal. These pores were not close to the surface of the specimen, which probably accounts for this good behavior.

The two 4320 filler wire welds with pores gave 9 and 2% weld-metal elongations. The difference in behavior was apparently due to the positions of the pores, i.e., close to the specimen center in the 9% specimen and within 0.010 in. of the surface in the 2% elongation specimen.

The mild steel filler weld with a pore gave 4% elongation in the weld metal; this is encouraging since its flaw was at the surface.

Thus, to summarize, the effects are inconclusive due to the apparent interrelationship of flaw position and to the uncertainty of producing the particular type of flaw which will provide a critical test. More work should be done in this area.

The same two filler wires were evaluated with the biaxial bulge test. Here again, however, the results were inconclusive because of surface stress-raiser effects.

Intentional Surface Decarburization. Results which have been reported above emphasize the marked dependence of the mechanical behavior on surface, or near-surface, defects. A summation of the data to this point would lead to the conclusion that grinding scratches, bead-edge stress raisers, and near-surface weld-metal pores whenever they are present and critically oriented with respect to the loading system, will cause fracture to occur after only marginal elongation. Therefore, the following experiments were designed to provide a more ductile surface by reducing the carbon content within a few thousandths of an inch of each surface. This decarburization was accomplished by normalizing and austenitizing with controlled atmospheres of argon plus either oxygen, air or carbon dioxide, rather than the usual pure argon. The results of this technique are discussed in terms of longitudinal weld and biaxial bulge data. Table 8 gives the uniaxial results. Only one of the three specimens contained a fracture surface flaw; this flaw was only 0.008 in. from the original specimen surface, a condition which is usually critical. Thus the 3% elongation exhibited is fairly encouraging.

Table 8—Longitudinal-weld Tensile Properties

Special treatment (performed after welding)	Specimen No.	Ultimate tensile strength, ksi	Tensile strength (0.2% offset), ksi	Elongation, % (in 1-in. gage) Base metal	Elongation, % (in 1-in. gage) Weld metal	Flaws observed in weld-metal fracture surface
Surface decarburized	50 1L	253	212	9	8	None
	50 2L	241	199	8	5	None
	50 3L	255	211	7	3	Pore, 0.020 in. diam, 0.008 in. from surface
20% cold rolled	82	248	203	10	9	None
	82	250	215	9	8[a]	None
	88	249	202	8[a]	6	Pore, 0.022 in. diam, 0.002 in. from surface

[a] Estimated from fracture appearance.

The biaxial results are given in Table 9. The hardness data describe the extent of decarburization which was obtained with the various furnace atmospheres. The surface hardnesses are in the range R_c 33–42 except for the argon plus 1.5% oxygen atmosphere specimens which were decarburized to a lesser extent. The depth of decarburization, defined as the point where the hardness traverse curve started to fall off rapidly, is 0.008 to 0.014 in. The benefit of these treatments is apparent in the total strain figures; their average (excluding the argon plus 1.5% oxygen group), 3.7%, compares favorably with the 2.4% obtained with the standard heat treatments (Table 4). The relatively few specimens exhibiting less than 2% total strain is also encouraging. The strengths, with this controlled decarburization, suffer only a nominal decrease of approximately 10 ksi on the average.

Homogenization. It was suspected that the reduced strain ability of the weld specimens was partially due to the casting microstructure (microsegregation, dendritic grain structure) of the weld bead as compared to the fine-grained forged structure of the base metal. Hence several specimens were homogenized after welding. The purpose of this treatment was to eliminate any composition segregation which might result from the freezing of the weld metal. The homogenization consisted of holding the specimens at 1800° F for 24 and 48 hr. This treatment gave a weld-metal microstructure which

Table 9—Biaxial Bulge Test Results[a] (Surface Decarburized by Indicated Treatment)

Specimen No.	Ultimate tensile strength, ksi	Yield strength (0.2% offset), ksi	Total strain, %	Hardness, R_c Surface	Hardness, R_c Core	Depth of low hardness, mils	Fracture initiation and direction[b]
Heat treated in argon plus 3% oxygen							
50	255	221	2.55	...	...	...	In bead L
51	224	220	1.25	35	54	10	Pore L
82	271	233	3.25	...	...	...	Parent metal L
86	281	243	2.08	33	54	14	Bead edge L
87	266	213	2.35	...	...	...	Bead edge L
Heat treated in argon plus an air leak							
106	299	235	3.59	...	...	...	In bead L
107	270	247	1.68	35	54	10	Parent metal T
111	317	242	5.81	35	54	8	In bead T
Heat treated in argon plus 25% carbon dioxide							
103	258	221	3.06	42	56	12	Bead edge L
104	269	212	6.52	...	...	...	Bead edge L
105	269	219	4.34	34	54	14	In bead T
112	268	218	4.79	38	56	12	.....
114	304	221	6.16	...	...	...	In bead T
Avg.	...	...	3.7	...	...	...	.....
Heat treated in argon plus 1.5% oxygen							
52	271	239	1.86	...	...	...	In bead L
53	270	250	1.74	49	56	6	Parent metal L
84	285	262	2.77	...	...	...	In bead T
85	277	243	2.41	...	...	...	Bead edge L

[a] These disk specimens contained a diametric weld bead.
[b] L—fracture parallel to weld bead; T—fracture transverse to weld bead.

Table 10—Biaxial Bulge Test Results[a] (Surface Decarburized and Cold Rolled)

Specimen No.	Rolling reduction of area, %	Ultimate tensile strength, ksi	Yield strength (0.2% offset), ksi	Total strain, %	Fracture comments: Direction to bead	Fracture comments: Cause
1	20	273	205	6.80	Parallel	Not apparent
2	20	277	227	6.00	Perpendicular	Not apparent
3	20	246	215	2.32	Perpendicular	Not apparent
8	20	265	213	3.92	Perpendicular	Not apparent
115[a]	20	256	213	9.57	Parallel	Not apparent
120[b]	20	333	238	6.55	Parallel	Not apparent
4	30	254	239	2.43	Perpendicular	Not apparent
5	30	281	233	4.70	Parallel	Pore
6	30	296	214	6.70	Perpendicular	Not apparent
7	30	288	223	5.80	Perpendicular	Not apparent
Avg	...	277	222	5.48	...	...

[a] These disk specimens contained a diametric weld bead.
[b] Decarburized in atmosphere of argon plus 25% CO_2, 2 hr 1700° F, 1 hr 1400° F. All others were decarburized in argon plus an uncontrolled air leak during normal heat treatment.

was virtually indistinguishable from the base metal after subsequent full heat treatment. However, any beneficial effects of these treatments on mechanical properties (bulge test) were not shown conclusively. The generally unimpressive total strain data which were obtained are inconclusive because of surface defects.

Cold Work After Welding. The final attempt to improve the behavior of the weld area was to cold roll the whole specimen after welding and annealing. This treatment provides two possibilities for improvement. It can enhance the weld bead metallurgical structure by converting the casting to a forging, and it can either eliminate flaws or rearrange them (both surface and subsurface) to an orientation which is less critical with respect to the loading system imposed. Actually both improvements were probably realized, although it cannot be ascertained which mechanism resulted in the major improvement in mechanical behavior. As with the homogenized specimens, the weld-bead microstructures of the cold-rolled specimen (either 20 or 30% reduction of area) were indistinguishable from those of the parent metal after subsequent full heat treatment.

Mechanical properties were determined with the uniaxial longitudinal weld specimen and the welded biaxial bulge specimen. Table 8 gives the uniaxial results.

The 20% cold-rolled specimen with a 0.010-in. pore unfortunately was not measured for elongation. However, the weld-metal area was only 2% less than the over-all elongation, and the fracture appeared ductile. A reasonable estimate, based on the other cold-rolled specimen elongations, is 8 and 6%, which is encouraging.

The biaxial bulge data for the cold-rolled specimens are given in Table 10. These specimens, however, were inadvertently decarburized in addition to cold rolling. The total strain values with this double treatment were very much improved. The average for the whole table is 5.5%, with no specimens exhibiting less than 2% and one as high as 9½%. These were the best values obtained with the biaxial bulge specimen.

Conclusions

The following general conclusions are indicated by the experimental data reported in this paper. The conclusions are based on mechanical property data of welded specimens which were subjected to uniaxial and biaxial loading conditions. The welding procedure utilized is discussed in the paper. The two most noteworthy details of this procedure are that no preheat was used and that particular attention was given to the cleanliness of all welding materials.

Except when otherwise noted, the conclusions are based upon the mechanical properties after full heat treatment (1700° F → 1600° F in argon atmosphere → air quench; double temper 600° F, 2 hr each).

1. Satisfactory welds were performed in this material in 0.080-in. sheet sizes as large as 12 x 12 in., and in small pressure-vessel girth welds, with no observed cracking difficulties and with no preheat requirement indicated.

2. Strengths in properly heat-treated, welded specimens, loaded uniaxially (both longitudinal and transverse to the welding direction) and biaxially, range approximately from 240 to 280 ksi ultimate, and 205 to 250 ksi yield.

3. Ductility behavior is more difficult to generalize because of the several loading systems used and because of the marked dependence upon flaws with particular orientations.

a. With the uniaxial weld test loaded transverse to the weld direction, measured elongations are comparable to the all-base-metal specimens of similar geometry. The fracture occurs at the junction of the heat-affected zone and the unaffected base metal. The weld metal itself does not strain in this test.

b. With the uniaxial weld test loaded parallel to the welding direction, the flaw sensitivity becomes evident. These specimens exhibit 7 to 8% elongation in the base-metal portion of their cross sections, and 6 to 7% in the weld metal itself, when no weld-metal flaws are evident in the fracture surface. However, when a flaw exists in the weld metal, i.e., a 0.010- to 0.020-in. diam pore or a comparable inclusion, and particularly when this flaw is within 0.008 in. from a surface of the specimen, the weld-metal elongation drops off to 0–2%. Base-metal elongations with these specimens are generally 4–5%. If these same flaws exist midway between the sheet surfaces, the weld metal will again show reasonable elongation (4%).

c. The biaxial bulge test is critical to flaws both transverse and parallel to the weld direction. Thus this test was able to demonstrate the importance of weld bead-edge irregularities, and of grinding scratches obtained when grinding the bead flush. The difficulties measured with this test, reported in terms of total strain, are 1 to 3%, with an average of 2.3%.

4. Refrigeration to −75° F after quenching and between each tempering cycle gave approximately 30 ksi higher strengths than comparable specimens which were cooled only to room temperature. Elongations in the tensile test were comparable with the two treatments.

5. Welding with lower alloy filler wires (mild steel and 4320) may have reduced the flaw sensitivity of the weld metal; however, only a limited number of tests were run with these wires.

6. Partial decarburization of the surfaces of the weldments during heat treatment increased the biaxial tension total strains to a range of 1 to 5% with an average value of 3.7%. Longitudinal tensile tests also suggested that decarburization

caused the weld metal to be less sensitive to a flaw near the surface (3% weld-metal elongation).

7. Cold rolling (20 or 30%) between welding and heat treatment also made the weld metal less strain sensitive. A specimen which contained a near-surface pore gave an estimated 6% weld-metal elongation.

8. The combination of cold rolling and surface decarburization gave the best ductilities. Biaxial bulge total strain results fell in the range of 2.3 to 9.5% with an average value of 5.5%. The strengths (biaxial bulge) with this treatment were approximately 250–300 ksi ultimate, and 205–240 ksi yield.

Acknowledgments

The authors are indebted to the International Nickel Co. and to Thiokol Chemical Corp. for sponsorship of the two programs which developed the data upon which this paper is based, and for their permission to publish the knowledge gained. Particular appreciation is acknowledged for the personal interest and guidance provided by Messers T. N. Armstrong and L. M. Petryck of Inco, and T. H. Burns of Thiokol.

APPENDIX

Description of Bulge Test and Methods of Data Reduction

A circular bulging disk is subjected to 1:1 biaxial stress at its center. This stress decreases as the edge of the specimen is approached in both degree of biaxiality and stress level. Accordingly, the strain that the bulging material undergoes also decreases away from the pole. The material at the pole is strained with reasonable uniformity over an appreciable area. Thus, it may be assumed that if the pole area contains strain-sensitive inhomogeneities (sensitive to strain in any direction in the plane of the specimen), these inhomogeneities will be strained to their limit regardless of their inherent strength, causing fracture of the specimen at low average strain. The bulge test discriminates between ductile and brittle zones; failure at low strain results if any portion of the pole is strain sensitive.

In development of the ARF bulge test, no great effort was made to obtain high precision. Such an effort would have resulted in a very time-consuming testing procedure, and would not have added appreciably to the intended value of the test.* Nevertheless, the test was developed to the point where a stress-strain curve could be calculated for each test with reasonable accuracy. The most significant parameters for the problem under consideration were strain and yield strength and these were the only two factors receiving major attention.

The initial problem in testing high-strength sheet materials was that of restraining the periphery of the specimen without inducing premature failure through stress raisers set up by gripping mechanisms. This was overcome with a gently corrugated die set which was used first to impress the corrugations into the materials prior to hardening them, and then to hold the edges during testing. The specimen is guided into the hemispherical bulged shape over a generously radiused contour on the upper die half. Figures 12 and 13 show the testing apparatus. The outside diameter of the specimen is 12 in., and the diameter of the free bulge is 7 in.

In order to calculate the stress experienced by the bulging disk, the radius of curvature of the disk must be known. This measurement was accomplished with the profilometer shown in Figs. 12 and 13, which is a distorting pantograph. One end of the moving arm slides in a horizontal slot. At approximately the middle of the arm a small wheel rides over the specimen surface on a diameter, and a pen records the contour on a card at the other end of the arm. To determine the radii from the tracings on the card, a set of master curves was prepared. It was assumed that the profile would always be circular (the error in such an assumption is small in hard materials), and the master curves were traced with the original apparatus from circular curves at radius intervals of 0.2 in., from 3 to 12 in. 0.5 in. from 12 to 25 in., and 1 in. from 25 to 36 in. The radius of a given experimental curve is determined by visually fitting the master curves which are reproduced on transparent sheets. The fit has been found to be excellent over the entire curve and interpolation is frequently possible. Pressure-radius curves are extrapolated to obtain the radius at bursting pressure.

The bulge specimen is fitted with a post-yield strain gage, which permits strains of at least 5%, and occasionally up to 10%, to be recorded. Normally, only a pressure-strain curve was plotted, from which the 0.2% offset yield pressure could be determined. To determine the elongation at burst, a simple relation was derived, assuming isotropic behavior, between elongation and reduction in thickness at the pole of the broken specimen:

$$E = \sqrt{\frac{T}{1 - T}} \qquad (1)$$

where:

T = reduction in thickness.
E = elongation.

Since the strain gage is located

* A detailed analysis of the bulge test is presented by W. F. Brown and G. Sachs in "Strength and Failure Characteristics of Thin Circular Membranes" *Trans ASME*, 241–251 (1948).

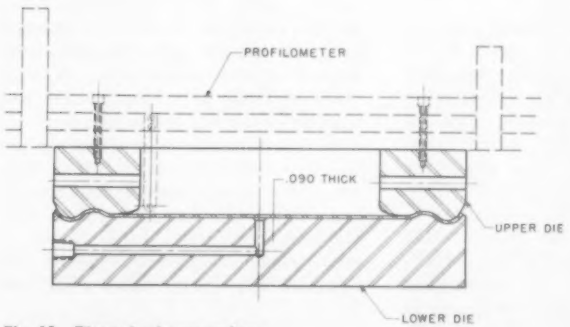


Fig. 12—Bluge test apparatus

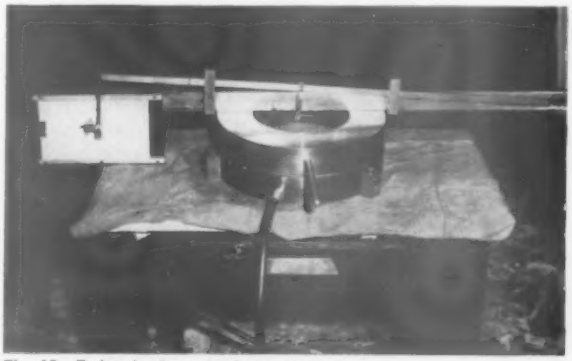


Fig. 13—Bulge test apparatus

with its center at the pole of the specimen and extends toward the edge of the specimen on a radius, some inaccuracy in the strain reading is to be expected. For purposes of comparison however, the method is considered satisfactory.

To calculate the stress at a given pressure level, the following relation* was used.

$$\text{Stress} = \frac{PR(1 + E)^2}{2T_0} \qquad (2)$$

where:

P = pressure in psi.
R = radius of curvature in inches at the given pressure.
E = elongation at the given pressure.
T_0 = original thickness in inches.

Substituting eq. 1 into eq. 2 yields:

$$\text{Stress} = \frac{PR}{2T_f} \qquad (3)$$

where T_f is the thickness at the pole of the specimen at the pressure level under consideration.

Bulge specimens were "crimped" or made to conform to the die by a pressing operation prior to hardening. If it was desired to leave a weld bead in the as-welded condition for test only, the outer $2^1/_2$ in. of bead was ground flush prior to crimping. It was found that the edge corrugations were little affected by heat treatment and, in fact, they help to keep the specimens reasonably flat on hardening. In most cases, however, when the press load (600 tons) was applied to the die, the specimens underwent some small strain due to straightening.

At no time was it necessary to use any form of gasket or other pressure seal with the apparatus. Normal variations in specimen thickness had no effect. In a few cases a leak developed when a weld bead was inadequately or excessively ground at the edge, but this could be stopped with a small amount of judiciously placed aluminum foil. It was found to be advisable to lightly sand blast the gripping surfaces of the die in order to insure that no slippage occurred. The die was designed to fit 0.090-in. thick sheet, but specimens as thin as 0.054 in. have been successfully tested.

Pressure was applied to the specimen with a manual pump, and read from a calibrated bourdon tube pressure gage scaled from 0 to 10,000 psi. Strain readings were taken at 200 psi intervals, and a profile was traced at 400 psi intervals. In the plastic range the pressure could not be held constant because of continuing deformation of the specimen; consequently strain readings and profiles had to be taken quickly upon reaching the desired pressure. With the thickest specimens (0.090 in.) bursting pressures sometimes exceeded 8000 psi; a separating force of about 300 tons was therefore active, so that a closure mechanism (i.e., press) with a capacity of at least 400 tons was considered desirable.

In reducing the test data, pressure-vs.-strain and pressure-vs.-radius curves were plotted. There is little deviation from a smooth curve except occasionally at low pressure, where the difficulty of comparing flat curves increases. To determine yield strength, the pressure at 0.2% offset was determined, as well as the radius (interpolated) corresponding to that pressure. Substitution of these values, along with the elongation for the given pressure, into eq 2 gave the yield strength. Burst radius was determined by extrapolating the pressure-radius curve to the appropriate pressure, and elongation at burst was calculated from eq 1 after measuring the reduced thickness at the pole.

* *Loc cit.*

EUROPEAN WELDING RESEARCH

By Gerard E. Claussen

FRANCE

The French welding magazine *Soudage Et Techniques Connexes* for March-April 1960 compares the reversed torsion fatigue strength of steel specimens 2-in. diam surfaced by metal spraying and by welding with low hydrogen electrodes $^1/_8$ in. diam. The metal spray wire contained 0.2% C and the same Mn and Si as the low-hydrogen electrode deposit. The electrode deposits governed the fatigue behavior of the shafts. If the deposit was unsound fatigue cracks occurred and propagated through the shaft. If sound, the deposit added to the fatigue strength. Metal spray deposits did not participate in fatigue strength, which was governed by the type of grooving used to prepare the shaft.

NETHERLANDS

A review of the metallurgy of electrode coverings is given by a Philips representative in the July 1960 issue of the Dutch magazine *Lastechniek*. The useful areas of the three fundamental ternary diagrams are drawn. The diagrams are: 1. SiO_2-Fe_2O_4-$CaCO_3$ for iron oxide and acid 6020 coverings, 2. SiO_2-TiO_2-$MgCO_3$ for rutile 6012 coverings, and 3. SiO_2-$CaCO_3$-CaF_2 for basic, low-hydrogen coverings. Molecules of FeF_2 are postulated in slags from low-hydrogen electrodes.

SWEDEN

The Swedish magazine ESAB's *Tidning Svetsaren*, No. 2 for 1960 contains a detailed examination of the microstructure and tensile and impact properties of electroslag welds. The only possible weak point revealed was the impact strength which was studied only with U notch specimens. A continuous induction normalizer was used to heat treat the welds.

In the same issue is a description of a new compact portable wire feeder for continuous electrode welding with shielding gas. For CO_2 welding horizontal butt joints in steel plate $^5/_8$-in. thick a 40 deg opening is recommended with low-

(*Continued on page 258-s*)

DR. GERARD E. CLAUSSEN is associated with Arcrods Corp., Sparrows Point, Md.

Weldability Prediction from Steel Composition to Avoid Heat-Affected Zone Cracking

Carbon equivalents are correlated with heat-affected zone cracking and with weldability data for high-strength steels

BY K. WINTERTON

SUMMARY. A review has been made of a number of formulas available for the prediction of the weldability of steels from their composition. In these formulas, the hardness, the ductility and the amount of cracking in the heat-affected zone have variously been used as criteria for weldability.

A new formula, based on end-of-transformation temperature (M_F) in the austenite/martensite transformation, is proposed for the calculation of equivalent carbon content (C.E.):

$$\text{C.E.} = \text{C } \% + \frac{\text{Mn, } \%}{6} + \frac{\text{Ni, } \%}{20} + \frac{\text{Cr, } \%}{10} - \frac{\text{Mo, } \%}{50} - \frac{\text{V, } \%}{10} + \frac{\text{Cu, } \%}{40}$$

Carbon equivalents calculated from this formula seemed to correlate reasonably well both with the heat-affected zone cracking data of previous authors, and also with new weldability data presented for a group of high-strength steels.

Any formula of this kind is an approximate guide to be used only in the absence of more reliable data.

Introduction

It would be useful if the weldability of a steel could be forecast from its composition. However, weldability in the general sense is so complex that it is unlikely that this will ever be possible.

In a more limited sense, if the term weldability is restricted to the single aspect of heat-affected zone cracking, there is a better prospect of predicting behavior from composition, since one of the factors controlling heat-affected zone cracking is hardenability, which itself depends on composition.

K. WINTERTON is Head, Welding Section, Physical Metallurgy Div., Mines Branch, Dept. of Mines and Technical Surveys, Ottawa, Canada.

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The uncritical or over-enthusiastic use of formulas* to predict the weldability of a steel (even in the restricted sense of heat-affected zone cracking) is to be deplored, since there is an implied simplicity which does not subsist. Nevertheless, for the following purposes the use of formulas may be justified:

1. In predicting the behavior of a new and unknown steel, in cases where time or money is not available for the proper assessment of weldability.
2. In assessing the effect of varying composition within prescribed limits. This could be useful for example in designing codes or specifications.
3. As a guide in the development of new and experimental steels.

Several formulas are already available but are in conflict, leading to widely different results. The present paper reviews these formulas and accounts for some of the differences between them. It is hoped that a sounder basis for such calculations is now provided.

Weldability Formulas

One of the earliest formulas used to assess weldability was:

$$\text{C.E.} = \text{C, } \% + \frac{\text{Mn, } \%}{6} \quad (1)$$

This was presumably abstracted from the more complex formula put forward by Dearden and O'Neill[1] which is dealt with later. The assumption in using such a formula would be that if the carbon equivalent exceeded a certain level, the steel would not be weldable without special precautions.

Voldrich, Martin and Harder[2] used formula (1) above, together with three others as given below (2, 3 and 4) for the assessment of some weldability test results:

$$\text{C.E.} = \text{C, } \% + \frac{\text{Mn, } \%}{4} \quad (2)$$

$$\text{C.E.} = \text{C, } \% + \frac{\text{Mn, } \%}{4} + \frac{\text{Si, } \%}{4} \quad (3)$$

$$\log_{10} \text{D.P.N.} = 1.957 + 1.41 \text{ C, } \% + 0.193 \text{ Mn, } \% + 0.086 \text{ Ni, } \% + 0.16 \text{ Cr, } \% + 0.03 \text{ Cu, } \% \quad (4)$$

Formula (4) above was originally developed by Edson[3] for calculating the Vickers hardness developed in the weld heat-affected zone. To facilitate comparison of the relative effectiveness of the various elements formula (4) may be expressed as follows:

$$\text{C.E.} = \frac{\log_{10} \text{D.P.N.} - 1.957}{1.41} = \text{C, } \% + \frac{\text{Mn, } \%}{7.3} + \frac{\text{Ni, } \%}{16.4} + \frac{\text{Cr, } \%}{8.8} + \frac{\text{Cu, } \%}{47} \quad (5)$$

These authors plotted the carbon equivalent obtained from these various formulas against the bend angle obtained for various steels in the notch-bead slow-bend test. Sixteen steel compositions were used in $^1/_2$, $^3/_4$, and 1 in. thickness, all within the following composition range—Carbon, 0.21–0.36%; Manganese, 0.37–1.62%; Silicon, 0–0.54%—with small amounts of nickel (0.2%), chromium (0.2%) and copper (0.3%).

The criterion used may be expected to give a rough measure of the ductility of the heat-affected zone, since as the latter becomes harder and more brittle, the angle of bend

* C. L. M. Cottrell has pointed out in a letter to the author that the formulas discussed here have been developed for the welding of alloy steel plates. They are not necessarily valid for sheet, e.g., high-strength alloy steel sheet for missile skins, etc.

which may be sustained in the test will decrease. When the welding conditions are severe enough to cause cracking in the heat-affected zone, a rather sharp drop in this angle would be expected.

Voldrich, Martin and Harder[2] concluded that formula (2) given above gave rather better results than the others.

From their results, the carbon equivalent from formula (2) should not be greater than about 0.54% in order that a maximum hardness of 350 D.P.N. should not be exceeded in the heat-affected zone. (NOTE: The suggested limit was put forward[1,4] in 1940 and has remained a useful guide.)

The same formula (2) was later used by Williams, Roach, Martin and Voldrich[5] in the evaluation of the same group of steels using a bead-on-plate cracking test. From their results, it appeared that the carbon equivalent (from formula 2) should not exceed about 0.38% to avoid cracking. (Somewhat higher values of 0.42 and 0.57% were permissible with 150 and 225° F preheat respectively.)

In a summary paper by Voldrich and Harder[6] dealing with the Battelle work,[2,5] there is a partial return to formula (1) from the point of view of the hardness developed in the heat-affected zone. The authors refer to the "generally accepted criteria for maximum underbead hardness, i.e., 350 Vickers maximum to insure absence of cracking and 250 Vickers maximum for satisfactory performance of the heat-affected zone under service loading, particularly in the structures which are to serve in the as-welded condition." The limits for carbon equivalent (from formula (1)) are as follows: to ensure that 350 D.P.N. is not exceeded requires less than 0.60% carbon equivalent for 1/4-in. plate, 0.50% for 1/2-in. plate, 0.45% for 1-in. plate and 0.40% for 2-in. plate; to ensure that 250 D.P.N. is not exceeded requires less than 0.45% carbon equivalent for 1/4-in. plate, 0.40% for 1/2-in plate, 0.35% for 1-in. plate and 0.30% for 2-in. plate.

However, Voldrich and Harder[6] found that it was convenient to make comparison using formula (3), "to account for the greater silicon content of the cast steels." From a graphical presentation of their results of tests on 1-in. thick steel, it is clear that the carbon equivalent calculated from formula (2) should not exceed 0.54% (to avoid exceeding 350 D.P.N.) or 0.40% (to avoid exceeding 250 D.P.N.). It should be noted that within this range 250–350 D.P.N., cracking was reported[6] to the extent of 5–42%.

Since 1949, formula (3) has been widely used and has been accepted by several authorities: for instance, it is quoted by Stout and Doty.[7]

Heuschkel[8] used the T-bend test to evaluate weldability, the welded fillets being stressed in tension by this test. Plate of 1/2 in. thickness was used, the test assembly being supported on 6-in. centers, and bent around a 1-in. diam former. The results were treated in a rather complex way, and he considers both "performance energy of deformation" and maximum bending angle as criteria. The steels used were in the following composition range: Carbon, 0–0.48%; Manganese, 0–1.62%; Silicon, 0–1.00%; Nickel, 0–3.10%; Chromium, 0–1.02%; Molybdenum, 0–0.41%; Copper, 0–1.06%; Titanium, 0–0.085%.

He found that the results depended on temperature and expressed then in the form of the following two formulas:

$$\text{C.E. } (70^\circ \text{ F}) = \text{C, \%} + \frac{\text{Mn, \%}}{10} + \frac{\text{Si, \%}}{9} + \frac{\text{Ni, \%}}{99} + \frac{\text{Cr, \%}}{10} + \frac{\text{Mo, \%}}{3} + \frac{\text{V, \%}}{6} + \frac{\text{Cu, \%}}{99} + \frac{\text{P, \%}}{1.4} \quad (6)$$

$$\text{C.E. } (-20^\circ \text{ F}) = \text{C, \%} + \frac{\text{Mn, \%}}{10} + \frac{\text{Si, \%}}{5} + \frac{\text{Ni, \%}}{28} + \frac{\text{Cr, \%}}{7} + \frac{\text{Mo, \%}}{3} + \frac{\text{V, \%}}{\infty} + \frac{\text{Cu, \%}}{28} + \frac{\text{P, \%}}{1} \quad (7)$$

Dearden and O'Neill[1] used as a criterion the hardness developed in the heat-affected zone of a Reeve test, for fifteen steels in 1/2 in. thickness. Their formula is:

$$\text{C.E.} = \text{C, \%} + \frac{\text{Mn, \%}}{6} + \frac{\text{Ni, \%}}{15} + \frac{\text{Cr, \%}}{5} + \frac{\text{Mo, \%}}{4} + \frac{\text{V, \%}}{5} + \frac{\text{Cu, \%*}}{13} + \frac{\text{Co, \%}}{150} \quad (8)$$

The compositions of the steels used were in the following range: Carbon, 0.10–0.31%; Manganese, 0.26 – 1.56%; Nickel, 0 – 5.38%; Chromium, 0–1.73%; Molybdenum, 0–0.64%; Copper, 0–0.65%; Vanadium, 0.14% (one steel only); Cobalt, 2.30% (one steel only).

For good weldability, they give a limit on carbon equivalent of 0.45%. The relation between Vickers hardness and carbon equivalent is given by:

$$\text{D.P.N.} = 1200 \text{ (C.E.)} - 200$$

The limit for hardness in the heat-affected zone is given as 350 D.P.N., although the authors believe that higher values may occasionally be encountered without cracking up to a maximum of 400 D.P.N.†

This formula (8) has been used to some extent and is quoted for instance in a handbook.[9] Various degrees of preheat are suggested when the carbon equivalent exceeds 0.45%.

Kihara, Suzuki and Kanatani[10] found that Dearden and O'Neill's formula worked quite well for the hardness developed in their wedge weldability test for a wide range of steels. They pointed out that Dearden and O'Neill[1] give no factor for silicon and suggested that Si/24 should be included in the formula. In addition, they give a slightly different relationship for the hardness developed:

$$\text{H(max)} = (666 \text{ C.E.} + 40) \pm 40$$

Reeve[11] tested a range of eleven N.D. steels (British Notch-Ductile Steels, B.S. 2762, in grades I, II, III and IV) in 1 in. thickness and with the following composition range: Carbon, 0.130–0.230%; Manganese, 0.87–1.62%; Silicon, 0.04–0.21%.

Controlled thermal severity tests and Battelle bead-on-plate tests were made on each of these steels. It was found that the former were slightly more severe.

Reeve found that formula (2) recommended by Voldrich and others[2,5,6] was not fully satisfactory for predicting cracking in the Battelle test. Slight cracking was obtained with a carbon equivalent of 0.52% for one steel, whereas in another steel with a carbon equivalent of 0.48%, no cracking was obtained. Reeve[11] states that the limit on carbon equivalent given by the Battelle workers is 0.40%. (It is true that this seems a reasonable value from an examination of the data on cracking.[5] However, for the 1 in. thickness, Voldrich

* This factor applies when the copper exceeds 0.5%; for smaller amounts the effect of copper may be neglected.

† Bradstreet has pointed out, in a letter to the author, that hardness is not a reliable indication of weldability. He cites the case of the British Welding Research Association Steel "D" for which a peak hardness of 426 D.P.N. was recorded in crack-free welds (Cottrell, Bradstreet and Jones, *Brit. Weld. Jnl.*, March 1956), and a plain carbon steel (0.5% carbon) for which a peak hardness of 450 D.P.N. was obtained (Bradstreet and Wilkins, *Brit. Weld. Jnl.*, December 1955). Moreover, Bradstreet points out that if preheating is used the criterion of hardness becomes even more questionable. He cites a case of crack-free welds with a peak hardness of 560 D.P.N. on a Ni-Cr-Mo (3 1/2% Ni) which was welded with 300° C preheat.

and Harder[6] in their summary paper give 0.45% as the carbon equivalent limit based on the 350 D.P.N. criterion.)

Reeve[11] also tried formula (8), recommended by Dearden and O'Neill,[1] for predicting behavior in the Controlled Thermal Severity test. In this connection, Reeve[11] points out that the latter is geometrically similar to the Reeve test used as criterion by Dearden and O'Neill. In effect, their formula (8) reduces to formula (1) in this instance, since the N.D. steels contain no alloying elements other than manganese. In this case the transition from not-cracking to cracking occurred with carbon equivalent in the range 0.400 ± 0.004% so that the limit is here much better defined. However, the actual value of the limit (0.40%) differs from the 0.45% suggested by Dearden and O'Neill.[1]

Sims and Banta[12] used as a criterion the amount of cracking obtained in the Battelle bead-on-plate test. Forty steels were examined in the following composition range: Carbon, 0.17–0.32%; Manganese, 0.93–1.51%; Silicon, 0.41–0.92%; Chromium, 0.28–1.0%; Molybdenum, 0.1–0.43%; Vanadium, 0.04–0.29%; Titanium, 0–0.038%.

The steels contained no nickel. Their results are given in diagrammatic form, plotting amount of cracking against increasing percentages of the various elements. The following approximate formula may be derived from these graphical relations:

$$\text{C.E.} = \text{C, \%} + \frac{\text{Mn, \%}}{7} + \frac{\text{Si, \%}}{25} + \frac{\text{Cr, \%}}{510} + \frac{\text{Mo, \%}}{31} + \frac{\text{V, \%}}{13} \quad (9)$$

Cottrell and others[13,14] have investigated the relationship between heat-affected zone cracking in the Controlled Thermal test) and dilatometric changes. There appeared to be a relation between liability to cracking and the end-of-transformation temperature in the austenite/martensite transformation. At one time, because of the paucity of information available, a formula of Nehrenberg[15] was used as an approximate guide to weldability, though strictly speaking this was designed to give the temperature for the start of martensite transformation:

$$M_s\ (^\circ\text{F}) = 930 - 540\ \text{C, \%} - 60\ \text{Mn, \%} - 20\ \text{Si, \%} - 30\ \text{Ni, \%} - 40\ \text{Cr, \%} - 20\ \text{Mo, \%} \quad (10)$$

For comparison with the other formulas, this may be also expressed in the following form:

$$\frac{930 - M_s}{540} = \text{C, \%} + \frac{\text{Mn, \%}}{9} + \frac{\text{Si, \%}}{27} + \frac{\text{Ni, \%}}{18} + \frac{\text{Cr, \%}}{14} + \frac{\text{Mo, \%}}{27} \quad (11)$$

There are several such formulas for the prediction of M_s temperature, but Cottrell found that of Nehrenberg[15] to give best results in connection with his own dilatometric data.

Later on, Bradstreet[16] put forward another formula based on the observed end-of-transformation temperatures for the same series of experimental steels as used by the previous authors[13,14]:

$$\text{C.E.} = \text{C, \%} + \frac{\text{Mn, \%}}{20} + \frac{\text{Ni, \%}}{15} + \frac{\text{Cr, \%} + \text{Mo, \%} + \text{V, \%}}{10} \quad (12)$$

The fifty experimental steels on which this formula was based were in the following composition range: Carbon, 0.12–0.20%; Manganese, 0.64–1.79%; Nickel, 0.07–1.59%; Chromium, 0.17–1.06%; Molybdenum, 0.21–0.27%; Copper, 0–1.13% (Four steels only with approx. 1% Cu); Vanadium, 0–0.23%.

From the carbon equivalent obtained from this formula, a weldability index letter is assigned, appropriate welding conditions then being in accordance with tabular data of Cottrell and Bradstreet.[17,18]

Assessment of Previous Formulas

In the derivation of weldability formulas, the criterion used is very important. Strictly speaking, one should not compare formulas based on bend angle in the notch-bead slow-bend test with those based on hardness developed in the Reeve test or cracking in the Battelle test. No doubt, these differences account in part for the diversity of the results.

Those criteria which depend on bending or some destructive evaluation of a welded assembly may complicate the issue by the introduction of a ductility requirement. This may result in too high an emphasis on those elements known to contribute to poor ductility such as silicon, phosphorus, etc. This occurs for example in Heuschkel's results, represented here by formulas (6) and (7). The importance of phosphorus in this connection may be judged by the factor of C, % + (20 × P%) put forward by McGeady and Stout[19] as correlating with the transition temperature of welded plates.

It is suggested that more significant formulas will be restricted to indicate cracking developed in standard tests, or to some factor which is known to correlate with this. "Peak hardness in the heat-affected zone" as defined and measured by Cottrell and others[13,14] seems to correlate well with cracking, but fairly wide differences in the critical hardness values obtained by different authors suggest that the techniques should be standardized if the results are to have any useful currency. Sims and Banta[12] are doubtful about the use of hardness or hardenability as criteria, since they point out that homogenization has an important influence in alleviating heat-affected zone cracking without much affecting the maximum hardness developed.

It is important that any formula should be based on a wide range of steel composition. This has not always applied in the previous work quoted. Thus in Sims and Banta's work, the effect of manganese is investigated with variation in the range of 0.9–1.5% manganese, and in assessing the effect of other elements, the manganese content was always in excess of 1.26%. In addition, all the experimental heats were deoxidized with aluminum, and with two exceptions titanium was added; both of these additions were later found to have an important effect. In the series of steels on which the formula of Bradstreet[16] is based, the carbon and molybdenum contents were both held constant in the main series.

The popularity of formula (3) which assigns an important influence to silicon seems to rest heavily on the work of Voldrich, Martin and Harder.[2] However, if their results are replotted using a carbon equivalent based on C, % + (Mn, %/10), the relationship with bend angle is equally as good as those reported by the authors. In fact, the authors themselves say, "The four graphs show a remarkable uniformity in the order of the plotted points and in the trend of the curves, regardless of the formula used for the carbon equivalent. For example it seems to matter very little whether the manganese factor is 1/5 or 1/4; in the upper two graphs these manganese factors were used and the curves are virtually identical."

Using the plot mentioned, or C, % + (Mn, %/6) as used by the authors, only the points representing the steels with high silicon con-

Table 1—Values of Manganese Factor for Formula (13) with Varying Carbon Content

Carbon content, %	Manganese factor	Carbon content, %	Manganese factor
0.10	32	0.24	13
0.12	27	0.26	12
0.14	23	0.28	12
0.16	20	0.30	11
0.18	18	0.35	10
0.20	16	0.40	8
0.22	15	0.50	6

tent lie off the main curve. When it is realized that the steels involved are cast steels, whereas all the others are wrought, the validity of introducing a silicon factor becomes doubtful. The results using cast steels (containing 0.30–0.80% silicon) seem to lie on a separate straight line from that characteristic of the wrought steels (containing 0–0.29% silicon). Why this should be is not clear, but evidently it may be for some other reason than the fact that they contain more silicon.

With regard to the effect of silicon, it may be noted that no silicon factor is given in formulas (1, 2, 5, 8 and 12) and is of low significance in formulas (9 and 11) and in the modification by Kihara and others[18] of formula (8).

A New Suggested Formula

Derivation

This suggestion is based, as in the case of Bradstreet,[16] on the observed relationship between heat-affected zone cracking and end-of-transformation temperature in the austenite/martensite transformation. The data is drawn from the U.S.S. Atlas[20] (and Supplement[21]) of isothermal transformation diagrams from which can be abstracted the temperature for 90% transformation (M_{90}) for a wide range of steel compositions.

The steels covered in the Atlas comprise a wide composition range, so that the effects of the competing elements can be more readily discerned: Carbon, 0–1.2%; Manganese, 0–2.0%; Silicon, 0–3.8%; Nickel, 0–8.9%; Chromium, 0–12.2%; Molybdenum, 0–2.0%; Vanadium, 0–0.27%; Copper, 0–1.5%; Boron, 0–0.0018%.

The 90% transformation temperature (M_{90}) is closely related to the end-of-transformation temperature (M_F) known to be related to heat-affected zone cracking.

The following relation fitted the available data best:

$$M_{90}\,(^\circ F) = 850 - (630 + 195\,Mn, \%)\,C, \% - 40\,Ni, \% - 80\,Cr, \% + 14\,Mo, \% + 85\,V, \% - 20\,Cu, \% \quad (13)$$

For average values of manganese content, single factors may be assigned to each element, and the formula rewritten:

$$C.E. = \frac{850 - M_{90}}{630} = C, \% + \frac{Mn, \%}{\alpha} + \frac{Ni, \%}{20} + \frac{Cr, \%}{10} - \frac{Mo, \%}{50} - \frac{V, \%}{10} + \frac{Cu, \%}{40}\ (approx.) \quad (14)$$

where α varies from 6 to 32 depending on the particular values of carbon and manganese content as shown in Table 1.

In formula (14), it may be noted that a negative value is assigned to the molybdenum and vanadium factors. The effects of these two elements are variable, sometimes depressing, but more often raising the M_F temperature. Their average effects are represented in the formula. It seems quite likely that in spite of an inherent depressing effect as alloys, their strong carbide-forming tendency leads to carbon being withheld from solution, causing a net elevating effect. The relative magnitude of the two opposing effects could then be decided by the time and temperature available for solution of carbides.

Formulas (13) and (14) are satisfactory for the calculation of the M_{90} temperature, and the M_F temperature may then be approximately obtained from:

$$M_F\,(^\circ F) = M_{90} - 114$$

(standard deviation $\pm 38^\circ$ F)

However, trials have shown that more weight must be given to the manganese content in predicting heat-affected zone cracking. The reason for this may be that in low-alloy steels, manganese has the most important influence on banding. Thus with carbon content in the range 0.10–0.30%, and sulfur content about 0.03%, manganese content above about 0.5% has an over-riding effect on banding, followed by carbon, then sulfur, other elements having an almost negligible effect when present in the usual amounts. The presence of high composition bands can result in premature cracking, and this explains the fact that high manganese content has a more important influence on cracking than the theory based on end-of-transformation temperature would suggest.

Prediction of Weldability (Heat-affected Zone Cracking)

The following modified formula may be used for this purpose:

$$C.E. = C, \% + \frac{Mn, \%}{6} + \frac{Ni, \%}{20} + \frac{Cr, \%}{10} - \frac{Mo, \%}{50} - \frac{V, \%}{10} + \frac{Cu, \%}{40} \quad (15)$$

After working out the carbon equivalent from formula (15), the procedures necessary to avoid heat-affected zone cracking may be found by reference to Table 2. The data presented should correlate best with tests of moderate severity such as the Battelle bead-on-plate test or the Controlled Thermal Severity test.

Table 2—Welding Precautions for Various Carbon Equivalents

Carbon equivalent	Welding procedure
<0.40	No precautions: Weldable with E6010 and E6012 electrodes
0.40–0.48	Weldable with: (a) ordinary electrodes and low preheat (200–400° F), or (b) low-hydrogen electrodes
0.48–0.55	Weldable with: (a) ordinary electrodes and moderate preheat (400–700° F), or (b) austenitic electrodes, or (c) gas-metal-arc welding
>0.55	May be weldable with: (a) low-hydrogen electrodes, and moderate or high preheat, or (b) austenitic electrodes, or (c) gas-metal-arc welding

Practical Application

Using formula (15), the results

of Williams, Roach, Martin and Voldrich,[8] show cracking in the Battelle bead-on plate test at 0.37% carbon equivalent, this being raised to 0.47% carbon equivalent for a preheat of 225° F.

Reeve's results[11] indicate cracking when the carbon equivalent exceeds 0.40%, this being a borderline figure for both the Battelle and Controlled Thermal Severity test.

Dearden and O'Neill's results[1] are also in agreement with a borderline value of 0.40%. One steel failed to crack with a carbon equivalent of 0.41%, and one steel cracked with less than the critical value.

A critical value of 0.40% for the carbon equivalent fits in with the results of Cottrell,[13] although two steels failed to crack with 0.42% carbon equivalent. The correlation in this case seems to be much better than can be obtained by other means. The lowest value of carbon equivalent for which cracking was obtained with low-hydrogen electrodes was 0.48%, although there were one or two instances where cracking did not occur with values of carbon equivalent slightly in excess of this (0.48–0.51%).

Bradstreet has pointed out in a letter to the author the specific result that Steel "D" (a steel developed by the British Welding Research Association,[13] has borderline weldability with low-hydrogen electrodes without preheat. The carbon equivalent, from formula (15), is 0.48, and this is again in line with the predictions set out in Table 2.

Some cruciform tests have been made in the Physical Metallurgy Division laboratories, Mines Branch, on the experimental and commercial steels indicated in Table 3. The testing technique has been described elsewhere.[24] The tests were made with baked high-strength electrodes with special low-hydrogen requirements.

The critical value of 0.51% carbon equivalent seems reasonable for the test conditions, i.e., intermediate between the values of 0.48% for ordinary low-hydrogen electrodes and 0.55% for gas metal-arc welding (where the hydrogen contamination is extremely small).

Limitations

It is emphasized that formula (15) is only an approximation and that its use is really only justified under the conditions put forward in the Introduction.

It does not take into account grain-size, deoxidation practice or prior heat-treatment though obviously all of these factors can have an important influence. The effect of aluminum has been dealt with by several investigators[11,12,24] and may be especially complex since apart from its alloying effect, nitrogen-removal, deoxidation and grain-size control are involved.

For a given test condition, a critical carbon equivalent should be assigned for each electrode type (with presumably a characteristic hydrogen level). In fact it is known that electrodes differ widely even within a given class with respect to the characteristic hydrogen level. Moreover this factor can be influenced by storage, atmospheric conditions, baking treatment or through contamination of the plate or electrode.

It is possible to treat hydrogen as an additional alloy constituent. Cottrell[23] has pointed out that in in the presence of 14 cc/100 g of hydrogen, typical of the figure associated with the deposits from good rutile-coated electrodes, the M_F temperature is depressed by 108° F for a manganese-molybdenum steel, and 144° F for a boron-molybdenum steel, consistent with the fact that hydrogen, like carbon, has a deleterious influence.

Table 3—Cruciform Test Results for Experimental Steels

Code or designation	Composition, % C	Mn	Si	Ni	Cr	Mo	Cruciform test	Carbon equivalent, (formula (15))
34[a]	0.15	0.85	0.15	...	...	[e]	No cracks	0.29
HY 80[b]	0.15	0.24	0.24	2.12	1.10	0.22	No cracks	0.40
33[a]	0.15	1.15	0.27	0.73	0.83	0.34	No cracks	0.45
26A[a]	0.18	0.31	0.18	2.11	1.54	0.38[e]	No cracks	0.48
HY 80[c]	0.15	0.21	0.23	2.97	1.85	0.46[e]	No cracks	0.51
29A[a]	0.19	1.20	0.25	1.27	0.75	0.49[e]	Cracked	0.52
R[a]	0.27	0.80	0.16	...	1.86	0.50[d]	Cracked	0.55
29[a]	0.20	1.48	0.33	0.08	1.08	0.51[e]	Cracked	0.55
Armor steel	0.28	0.88	...	0.62	1.02	0.32	Cracked	0.55

[a] Experimental steels. [b] Low composition. [c] High composition. [d] Plus 0.34% vanadium. [e] Plus 0.04–0.27 columbium.

Use of Formula (15) for Steel Design

Usually in developing a new steel composition, good weldability is only one of several desirable characteristics to be kept in mind.

From the welding point of view alone, molybdenum and vanadium seem to be highly desirable strengthening elements from among those examined here. Presumably other strong carbide formers would also be effective. It is interesting that Sims and Banta[12] have found titanium and vanadium good from this point of view.

Carbon content level evidently should be rigidly controlled and as low as possible consistent with the strength required.

In normal practice, manganese may be about equivalent to carbon from the point of view of the increase in cracking for a given increment in tensile strength. However, if the arguments put forward here are correct, it may be that manganese has an inherently rather mild effect in promoting cracking (particularly at low-carbon levels) but that this is normally obscured by the banding which it promotes. It is very interesting to note in this connection that Sims and Banta[12] found that a homogenizing treatment had a very beneficial effect on a steel containing 1.51% manganese, the cracking being reduced from 59 to 9%. It may be that some commercial heat treatment is possible to take advantage of this effect in improving the high manganese steels, though Sims and Banta[12] point out that the times involved are rather lengthy when treating slabs, and that undue scaling may occur at the higher temperatures required, when treating plates.

The addition of boron is another useful means of increasing strength without much detriment to weldability. However, one of the most effective ways of increasing strength without impairing weldability is by means of heat treatment. Quenched and tempered steels are used at the highest strength levels, but heat-treated steels might be used more extensively for ordinary structural work.

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EUROPEAN WELDING RESEARCH

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hydrogen electrodes for the root pass and to fill the upper edge of the second CO_2 pass to complete the joint. For double Vee butt joints in $1^3/_{16}$-in. steel plates, an included angle of 100 deg is recommended with $^5/_8$-in. root face and $^1/_{32}$-in. root spacing. One pass from each side at 660 amp, 43 v, 20 ipm, $^5/_{64}$-in. electrode containing 0.10 C, 1.5 Mn, 1.0 Si, was recommended. The high current restricts the practice to fully automatic welding.

USSR

Automatic Welding

The Russian magazine *Avtomaticheskaya Svarka* contains the following articles in its August 1960 issue:

• A formula is derived for the effect of internal stress created by welding on the instability of welded plates, in particular, a web plate of a girder with stiffeners. Graphs show the reduction in permissible design stress with increase in width-to-thickness ratio and with increase in internal stress.

• Fatigue and impact tests showed that joints in 0.50% C steel welded with covered electrodes and 570° F preheat were as good as those welded without preheat but stress relief heat treated at 1170° F. The preheated joints were free from the cracks sometimes found in stress relieved joints. The necessary preheat for steel containing 0.31 C, 0.62 Mn, 0.16 Si was 300 to 390° F.

• A low-hydrogen electrode was developed to weld ship plate containing 0.08 C, 0.61 Mn, 0.80 Si,0.89 Cr, 0.80 Ni, 0.41 Cu. The coating contained 50% $CaCO_3$, 17% CaF_2, 8% SiO_2, 1% bentonite, 1.5% soda ash, 32% sodium silicate, 2% Fe-Mn, 9% Fe-Ti, 3% Fe-Si, and 4 to 10% FeCr.

• The sigma phase in Type 310 weld metal heated 1000 hr at 1470° F contained 51.8 Cr, 44.7 Fe, 3.0 Ni, 1.1 Si, 0.6 Mn.

• Formulas are derived for calculating the welding conditions required to produce spot welds of geometrically similar dimensions in a range of sheet thicknesses, and to produce cross-wire welds. The formulas are based on the electrical and thermal constants of the metal to be welded.

• Single-phase and three-phase transformers are designed for multiple-electrode spot welding. A formula is given for short circuit resistance.

• A economic study of welding for coal mines showed that costs per pound of weld metal were less than half as high in plants with specialized welding departments, than in plants not specializing in coal mining structures.

• Two methods of surfacing steel parts with aluminum bronze are described. In the first method a large copper wire and a small aluminum wire are mashed together by the feed rolls of an automatic arc welding head, and the composite electrode thus formed is deposited. The second method involves electroslag welding with strip or bar electrodes of aluminum bronze, and a flux containing 20% CaO, 80% CaF_2.

• The application of submerged-arc welding with squirt guns and automatics to the fabrication of diesel locomotive frames is described. In one type of frame requiring 535 lb of weld metal, 45% was deposited by submerged arc.

• The water cooling of seam welds in 0.08% carbon steel during welding to reduce distortion reduced the ductility in a bend test from 10 bends for sheet to 5 bends for weld. Failure occurred in the hard zone close to the weld. By restricting water flow so that the weld tempered itself, the number of bends was increased to 8.

• CO_2 welding was applied to corner and butt welds in the manufacture of forging presses, and to the surfacing of 0.43% C steel with mild steel wire.

Production Welding

• *Svarachnoe Proizvodstvo* for Sep-

(Continued on page 264-s)

Development of New Nickel-Base Brazing Alloys Having Ductility

Molybdenum-manganese additions to nickel-base brazing alloys are found to increase ductility and wettability

BY R. A. LONG

SYNOPSIS. Methods of developing a new nickel base brazing alloy system are based on the tertiary system, nickel-molybdenum-silicon. The effect of additions of manganese, chromium, tin, lithium and beryllium are discussed, and the characteristics of specific alloys developed within the base alloy system are outlined.

Throughout development, casting technique and wetting tests as a screening method were combined for selecting the more appropriate alloys. Slight changes in chemical composition resulted in brazing alloys within the base alloy system that have different characteristics including good ductility.

Introduction

"Brazing" has been defined as a method of joining two or more metal surfaces by the use of another metal or alloy whose melting point is lower than those of the base metals but higher than 900° F. Metallurgically and in the light of relatively recent advances, it would be better to add to this definition by including " . . . and the process taking place at a temperature sufficient for the filler metal to flow-on and alloy-with the adjoining metal surfaces by fusion and/or diffusion." This terminology then attributes to "brazing" the ability of the filler metal to alloy with the base metal.

The words, "alloy" and "fusion," can no longer be attributed only to welding processes. High temperature brazing, also a generally misdefined phrase, has been either referenced to that type of brazing which is accomplished at temperatures in excess of 1750° F, to assemblies which must operate at temperatures in excess of 600° F, or to the general field which utilizes nickel base brazing alloys. At present, all usages are correct and part of a general definition.

The majority of nickel base brazing alloys commercially available in 1959 were originally developed for hard surfacing applications. As a result they have little "as cast" ductility and are generally classified as brittle. There are many applications where these alloys are, were and will always be suitable; on the other hand there are also many applications of these alloys which have been misused.

Hard surfacing alloys of the Ni-Cr-B and Ni, Cr, B, Si variety were used in initial brazing applications because their flow temperatures were low enough so that commercially available atmosphere furnaces could be utilized. Furthermore they contained sufficient chromium to make the alloy oxidation resistant as reported by Peaslee and Boam in 1950 covering work done at Curtiss Wright Corp.

Developing new braze filler metals dictates a series of conditions which imposes on the metallurgist a program of seemingly nonending variables and limitations. There is no other field in which an alloy, both in the molten and solid state, has to meet so many fundamental requirements. Thus this paper describes both a newly developed alloy series and a method of development which obtained results with minimum effort.

Some Basic Considerations

Chill Cast Requirements

What is a brazing filler metal? When examining this question, one notes foremost that it is a metal or alloy cast between two metal surfaces which have higher melting points. As a result, the filler metal or alloy then solidifies while in contact with these surfaces. Therefore, a key attribute of such a filler metal is that it is first a chill casting alloy. With this in mind, one can then examine the known technology of casting alloys to establish a base for the development of brazing filler alloys. In doing so, the requirements for good casting alloys are found to be:

1. High fluidity
2. Minimum tendency to crack during cooling
3. Maximum soundness qualities after solidification.

High fluidity of a molten metal is a quality based on its composition and the casting temperature. It is well known in casting art that eutectic and near eutectic compositions have higher fluidity than pure metals or solid solution type alloys. In addition, the higher the casting temperature, the more fluid is the molten metal. This latter can overcome low fluidity due to composition and is the basis for using higher casting temperatures for some alloys.

An alloy having a minimum tendency to crack during the cooling cycle is dependent on the alloy's ability to locally deform when it is subjected to thermal stresses. Hot ductility is, therefore, a virtue. Tendency of a "just cast" alloy to crack during cooling is also dependent on whether the alloy is subject to hot shortness. In casting technology, hot shortness is restricted to certain compositions and about fifteen percent of a liquid phase by volume creates a maximum susceptibility to hot shortness cracks.

Soundness qualities of a solid cast alloy are based mainly on minimizing the gas content, volume shrinkage and microshrinkage. The former is controlled by deoxidation practices and the latter two, respectively, by utilizing adequate molten metal feeding (risers, gates, etc.), and selecting an alloy composition with a small melting interval (narrow range liquidus-solidus).

R. A. LONG is Manager, Refractories Research Dept., Research and Development Div., Narmco Industries, Inc., Telecomputing Corp., San Diego, Calif.

Paper presented at AWS National Fall Meeting held in Detroit, Mich., Sept. 28–Oct. 1, 1959.

Table 1—Data for Basic Experimental Alloys

Alloy designation	Chemical analysis,% Ni	Mo	Si	Mn	Fe	Approximate liquidus, °F	Approximate solidus, °F	Hardness RC
1A	61	23.77	13.47	0.17	1.19	2125	2075	50-61
2B	70.92	17.37	10.34	0.07	0.65	2100	2075	50-51
3C	72.77	17.34	10.12	0.09	0.49	2100	2050	50
4F	78.1	13.75	7.35	0.09	0.46	2180	2125	45

It is of interest to mention here that pure metals and eutectic alloys solidify with considerable shrinkage, and proper feeding heads are required to prevent "pipe." These same pure metals and eutectics do not show microshrinkage defects because of their narrow melting point range (theoretical melting temperature).

Brazing Mechanism Requirements

In addition to having to fulfill the above "chill cast" requirements, the metal or alloy to be useful as a brazing alloy must meet additional specific requirements which are peculiar to the field of bonding metal surfaces:

1. The molten filler metal must form low contact angles with the base metals being joined to assure good wetting and capillarity at a temperature which will not adversely affect the base metal properties.
2. The molten filler metal must be capable of alloying with the base metals by either fusion or diffusion without forming undesirable brittle phases within the joint interfaces, and without serious eroding. (Eroding is a "fusion time function.")
3. The molten filler metal must not lose necessary alloying elements by volatilization at the maximum possible brazing temperature.
4. The filler metals brazing cycle requirements of temperature and time must be within commercial heating methods.
5. The filler metal, if of a minimum alloying variety, must not soften appreciably if the joint assembly is to be operated near or above such softening temperature.

End Product Considerations

The metallurgist must, in his selection of a possible alloy system and a specific filler metal, keep in mind the requirements stated. He must also consider the role his final product will play on any joint which is to be braze bonded. Hence, he must give consideration to:

1. The chemical characteristics of the base metal or alloys.
2. The necessary limiting temperature and time to which the base metal can be heated (generally limited by the heat treat requirements).
3. Stresses to which the joint will be subjected.
4. The joint gap that must be joined together.
5. The corrosion couple that may be established.

All these requirements are basic to the selection of any specific brazing alloy.

Alloy System Development

Range of Systems

Alloy systems based on platinum, palladium, gold, cobalt, nickel, titanium and copper were all initially considered. Literature, data, evidence of previous work and phase diagrams eliminated from consideration all systems except nickel-base and titanium-base alloys. Both systems indicated possibilities. Literature data were available on the susceptibility of titanium-base materials to hydrogen and oxygen gas pickup, and it was felt that the resulting brittleness could be a limiting factor even if an alloy could be developed under laboratory conditions. Also hydrogen and dissociated ammonia could not be used as a protective gas atmosphere, and this would be a serious limitation. Nickel-base alloys as the basis of hard surfacing alloys, and many of the present brazing alloys were characterized by high-hardness and minimum ductility.

Elements known to be most effective from the literature data in lowering the melting temperature of nickel were copper, boron, beryllium, manganese, phosphorus, titanium and silicon. These elements are also effective hardeners for nickel; thus, the possibility of obtaining ductile binary alloys of low melting point were considered slight.

Tertiary and quaternary combinations were then considered, with emphasis on obtaining eutectic or near eutectic combinations. In this respect, the "Hastelloys" are well known nickel-base investment casting alloys having high strength and oxidation resistance at elevated temperatures. Since a number of these alloys contained 15–30% molybdenum, phase diagrams on the nickel-molybdenum systems were carefully studied. Tertiary diagrams in which the third element was one of the known nickel melting point depressors were searched for information. Few diagrams were available. However, a tertiary diagram Ni-Mo-Si was found published by Pfautsch in *Zeitschrift Für Metallkunde* in January 1925. This diagram showed considerable interest, and decreasing hardness readings indicated a possibility of ductile alloys at low silicon contents although no data on melting ranges was given. One could expect, however, that melting points below 2200° F would be possible because of the nickel–10% silicon binary eutectic which melts at 2100° F. The only question would be that of how molybdenum additions affect the binary alloy melting point.

Test Program

A program was established to determine characteristics of Ni-Mo-Si systems with nickel contents in excess of 60% and varying molybdenum contents. Table 1 shows four basic experimental alloys covering the range from 61% nickel to 78% nickel (14 to 24% molybdenum). The ratio of molybdenum to silicon was kept constant at about 1.75:1. Maintaining this ratio constant was felt necessary to minimize the number of variables at this stage of the development. It was later shown by liquidus temperature tests that the preferable ratio was between 2:1 and 2.75:1. Alloys outside this ratio had too high a liquidus temperature—well outside the present range of commercial brazing flow temperatures.

Experimental alloy ingots were cast in air at pouring temperatures of 2500° F; all showed good casting fluidity. Alloys 1A, 2B and 3C cracked in the mold upon solidification. However, alloys 2B and 3C showed less cracking tendency than 1A. Alloy 4F showed no cracking. After solidification, all ingots were fractured or cut, and their surfaces macro-etched. Alloys 1A, 2B and 3C showed evidence of hot shortness, again in decreasing order. Alloy 4F showed no hot shortness and an acicular grain structure. Gas porosity also decreased as the nickel content was increased. Alloy 1A had a high variable hardness across the ingot cross sections. Alloys

2B and 3C had a slightly lower, more constant hardness, and 4F had a constant 5 points lower hardness (Rc 45).

Screening Tests

In order to determine if these alloys were suitable for braze-bonding applications, a few screening tests were made. Chips from each of the alloys were heated to 2100° F in a dry hydrogen atmosphere in crucible boats and on a low carbon steel surface. All alloys showed some degree of melting and wetting. Alloys 1A and 4F showed less than 2B and 3C, indicating that, with too high or too low a nickel content, the melting point tends to increase.

Samples of each alloy were pulverized; melting and wetting tests were conducted on 304 stainless steel at 2100° F in dry hydrogen atmosphere. Again, alloys 1A and 4F showed little or no melting while 3B and 3C showed complete melting and some degree of wetting. At 2150° F, alloy 1A completely melted while 4F showed only about 10% melting. Difficulty in pulverizing showed that ductility of the alloys increased as the nickel content increased.

Stainless steel 304 overlap specimens were brazed using 1A, 2B and 3C alloys. All lap specimens showed some degree of joint bending, however, alloy 3C showed a larger degree of joint bending ductility. To compare the wetting characteristics of these alloys, a dimpled 304 stainless steel specimen with three controlled depth scratches radiating from the dimples was devised. Material from each alloy was placed in the dimple, and the samples were heated to 2200° F in dry hydrogen atmosphere and held for about 5 minutes. Samples 2B and 3C showed considerable spreading and capillarity. The same tests were repeated at 50° F intervals down to 2000° F.

Results of the above screening tests indicated that alloys 2B and 3C showed good possibilities. In order to determine whether the air casting was responsible for their apparent brittleness, alloy 3C was investment-cast in a vacuum atmosphere. Three $^1/_4$-in. diam bars and tensile test bars were obtained. The casting technology was carefully analyzed for casting data information, and the pouring data sheet stated, "The material poured easily, and had good fluidity (2210° F). The metal layed still in the molds without tendency for outgasing or mold reaction. No significant vaporization occurred. Metal was free from slag."

Table 2—Effect of Manganese Additions

Alloy designation	Chemical analysis, % Ni	Mo	Si	Mn	Approximate liquidus, °F	Approximate solidus, °F	Hardness RC
5H	72.74	17.0	9.6	...	2100	2050	50
5H-5	71.3	16.6	8.2	3.9	2100	2000	50
5H-10	70.24	14.8	6.9	7.9	2025	1875	47.5
H-15	66.25	14.94	6.4	12.35	1950	1825	45.5
5H-17	62.5	13.1	7.5	16.9	1875	1780	45.0
5H-20	61.7	15.0	5.8	17.4	1850	1800	46.0
5H-25	57.5	15.0	5.4	22.75	1830	1775	44.0

The tensile bars were tested and showed less than 0.5% elongation. Ultimate tensile strength averaged 58,000 psi. All tensile bars had been X-ray sound. Melting and wetting tests of this vacuum cast alloy on stainless steel indicated about the same as the air cast 3C alloy previously tested.

In general, the screening test data of the first four analyses indicated that, as the nickel content increased (Molybdenum-silicon content decreased), the alloys became less hard and more ductile—at, however, a sacrifice of an increasing liquidus-solidus temperature.

Manganese Additions

Manganese in large percentages (eutectic at 40% nickel) is a known nickel melting temperature depressor as shown by the binary Ni-Mn diagram. Nickel and manganese also form a complete solid solution. It was of interest, therefore, to determine what effects manganese additions would have on the casting and bonding characteristics of the tertiary base system.

Alloy 5H in Table 2 was used as a base alloy; this happened to be the previously vacuum-cast 3C alloy and which was redesignated 5H because of the slight difference in chemical analysis. Crucible indication melts and button castings were made using this base alloy with manganese additions. Table 2 gives the results. It will be noted that, as the manganese content increases, the liquidus-solidus temperatures decrease. Hardness also tends to decrease slightly. The range between liquidus and solidus which increased slightly over that of the base 5H alloy with the first manganese (4%) additions tends to decrease with higher manganese additions. Examination of the cast slugs of these alloys revealed that alloys containing up to about 13% manganese are ductile and can be hammered without fracture. On the other hand, alloys over 13% manganese are less ductile than those below 13% but are still more ductile than alloys containing no manganese. Hot short cracks were not noted in any of the cast buttons.

The cast buttons were machined to obtain chips and granules for determining bonding characteristics. The approximate liquidus and solidus temperatures reported were obtained by conducting melting tests in dry hydrogen atmospheres on stainless and Inconel specimens.

Additional tests were conducted to determine flow, capillarity, erosion and lap-joint peel strength. All of the manganese-containing alloys showed good flow and capillarity—and the higher the manganese content, the better the flow at the liquidus temperature of that particular alloy. Other tests indicated that the lower manganese alloys had greater surface tension and thus, lower flow. Alloys with increasing manganese content showed increased base metal erosion (alloying) on both stainless and Inconel type alloys, the erosion or alloying increased with superheat temperature above the liquidus temperature.

Figure 1 shows the stainless and braze metal interface structure for

Table 3—Effect of Chromium Additions to Alloy 5H

Alloy designation	Chemical analysis, % Ni	Mo	Si	Cr	Approximate liquidus, °F	Approximate solidus, °F	Hardness RC
5H-0-5	69.1	16.66	9.52	4.76	2175	2080	50
5H-0-8	65.9	15.9	9.1	8.51	2175	2030	50
5H-0-10	64.8	15.6	8.9	10.7	2175	2070	48
5H-0-13	63.1	15.2	8.7	13.4	2175	2080	48

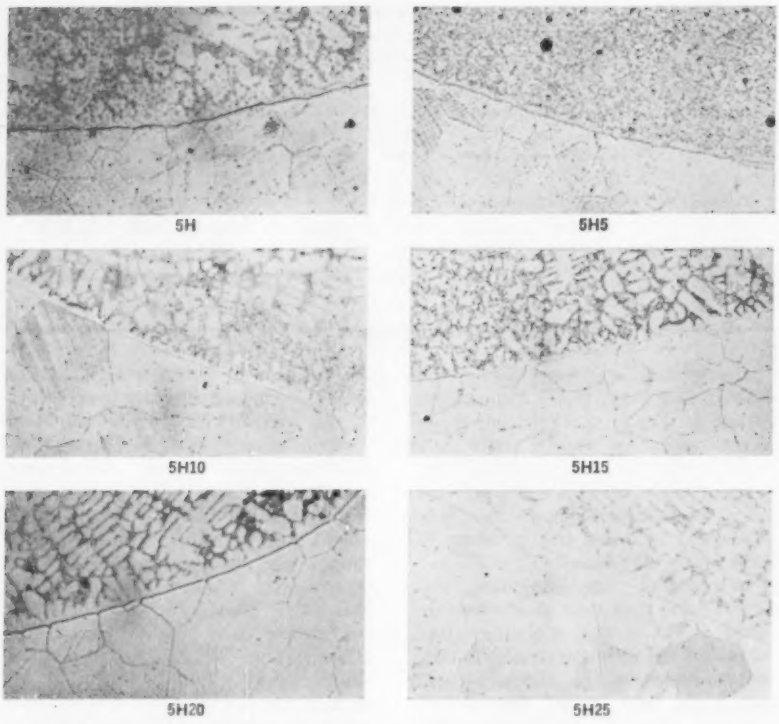


Fig. 1—Braze metal-base metal interfaces: 5H alloy plus varying manganese per cent additions; 2200° F, 5 min at temperature, hydrogen atmosphere, 304; stainless steel, × 100

all the alloys with increasing manganese contents can be noted. Also to be noted is the change in braze alloy cast structure at about 5H-10 (8% Mn) alloy. Peel strength increased with increased manganese content as more fusion alloying took place. This, of course, could be expected. An interesting observation was the excellent flow and bonding of alloys containing over 17% manganese to copper metal. Excellent joints were made and copper failures occurred during peel strength tests.

Oxidation-resistant nickel-base alloys almost always contain chromium, and the solid solution combination is well known in the art. Additions were made to the base alloy 5H in order to determine the effect of chromium additions on solidus-liquidus temperature, hardness and wetting characteristics. The results are shown in Table 3. Hardness decreases slightly with additions of up to 13% chromium. However, the liquidus-solidus temperature range is raised on the average about 75° F. Luster appearance of the cast button is improved. Wetting tests showed the same increase in luster appearance.

Cobalt and iron were separately added to the 5H base alloy in varying percentages, but no benefits were evident and the effect was more to broaden the range between the liquidus and solidus. These additions proved useful only in modifying these alloys to "wide gap" alloys.

The conclusions of these screening tests indicate that additions of manganese were most effective in lowering the liquidus-solidus range and in increasing the alloy wetting characteristics. Chromium additions were not detrimental except in so far as there was an increase in the liquidus temperature. Cobalt and iron were not beneficial.

Formulation of New Brazing Alloys

Many possible specific brazing alloys can be formulated from the base alloy system previously investigated. Since the basic purpose was to develop a ductile alloy, a high nickel content and a low molybdenum-silicon content was felt to be necessary.

The alloy series selected for further study was designated 4F and consisted of a higher nickel content and lower total molybdenum-silicon content. This choice was to obtain ductility characteristics. Table 4 describes the results on four different alloys containing manganese and manganese-chromium. The higher the manganese, the lower the liquidus-solidus range and the harder the alloy. Lowering the manganese content to about 15% and adding chromium gave alloys with slightly higher flow temperatures, better residual luster and lower hardness. All alloys in this group were somewhat ductile in that they could be cold hammered; however, alloys containing both manganese and chromium were specifically ductile. In 4F-18-5, the chromium seemed to counteract the hardening effect of the higher manganese content. This is, of course, beneficial.

The results of some side investigations are of interest and are shown in Table 5. Tin and beryllium additions in small percentages were found to be of value. The phase diagrams for nickel-tin and nickel-beryllium indicate that both form terminal solid solutions and both should give age hardenable characteristics to the braze alloy. After producing an alloy containing 5% tin, it was noted that there was an unexpected lowering of the liquidus-solidus range by about 70–100° F. The use of tin in other nickel brazing alloys should be given consideration because of this effect. Other test data indicate tin additions are not detrimental. Beryllium additions increased hardness as could be expected, particularly if there was a precipitation hardening effect during cooling. Again, a heat-treatable brazing alloy may have considerable benefit.

A further side investigation worthy of mention was that involving the addition of a small percent of lithium to a nickel base alloy. It was felt that lithium silicide could be used to introduce the lithium to the molten alloy and that the molybdenum in the alloy would

Table 4—Relation Between Manganese Content, Liquid-solidus Range and Hardness

Alloy designation	Chemical analysis, %					Approximate liquidus, °F	Approximate solidus, °F	Hardness R C
	Ni	Mo	Si	Mn	Cr			
4F-23	67.1	9.3	4.8	19.8	...	2000	1925	43
4F-18-5	63	8.34	4.18	18.4	5.7	2075	2000	34
4F-13-10	63	9.0	4.6	13.0	10.0	2170	2100	30
4F-8-15	63	8.9	4.1	8.0	15.2	2170	2100	31

stabilize and effectively tie up the lithium elements. There was considerable evidence that this was the case, since the alloy to which lithium had been added showed greater wetting on both stainless steel and Inconel than the same alloy without lithium. Chemical analysis of the lithium containing alloy indicated 1% lithium, but there was some doubt that this analysis was correct since only 1% lithium was added and full recovery of the lithium was not felt possible.

The developed alloys all have excellent flow and wetting characteristics particularly when a superheat of 50–100° F is used. This means that they will braze together close fit joints ranging from press fits to 3 mil gap thicknesses. Larger gaps than 3 mil are difficult to fill because of the narrow range between liquidus and solidus temperature of most of the alloys.

The recent tendency in the field to produce braze alloys, which would fill larger gaps because of production tolerances, led to another investigation worthy of reporting. It had been noted early that iron and cobalt broadened the liquidus-solidus range. Additions of 2% iron to alloy 4F-18-5 of Table 4 resulted in an increase in liquidus temperature to 2200° F or a 200° F range between liquidus and solidus. This permitted up to 10 mil brazing gaps. Another alloy with cobalt as an additive for brazing larger gaps contained 69.3% nickel, 16.7% molybdenum, 9% silicon and 5% cobalt. This had a solidus of 2030° F and a liquidus of about 2180° F.

Oxidation resistance of these alloys was determined at 1800° F for 13 hr in still air. These tests were conducted mainly because of still-air catastrophic oxidation problem of molybdenum and because of general belief that all alloys containing molybdenum are subject to this problem. All alloys tested showed little weight loss. Alloy 4F-23 showed less than 0.5% weight loss and contained the highest manganese percentage and no chromium. Alloy 5H-5 with the highest molybdenum content (16.6%) showed a total 5% weight loss. A control sample of GE81 alloy (70% nickel–20% chromium and 10% silicon) showed a 7% weight loss, and this alloy contained a high percentage of chromium and silicon. The results indicated that a molybdenum content up to 17% does not adversely affect oxidation resistance.

The previously obtained data were analyzed, and six alloy compositions were selected for further consideration. The composition, liquidus temperature, braze flow temperature and hardness are shown in Table 6. The first three of these alloys were produced in powder form by atomization. The latter three alloys were produced in shot cast form. Alloys 131-1, -2, were vacuum cast into tensile test bars.

Table 5—Effects of Tin and Beryllium Additions

Alloy designation	Chemical analysis, % Ni	Mo	Si	Mn	Sn	Be	Li	Cr	Liquid-solid range, °F	Hardness RC
5H-17-1 Li	61	12.5	7.2	17.4	...	...	1.0	...	2125	43
5H-17-21/2 Be	58.6	12.5	7.2	17.4	...	2.5	...	...	2100	47
5H-17-5 Sn	60.5	12.1	6.9	17.4	5.0	...	...	...	2000	40
4F-8-10-5	63.0	8.9	4.1	8.0	5.0	...	...	10.0	2100	30

Table 6—Chemical Analyses for Those Alloys Produced by Atomization and Three Alloys Produced in Shot-cast Form

Alloy designation	Chemical analysis, % Ni	Mo	Si	Mn	Cr	Sn	Fe	Liquidus temperature, °F	Braze flow temperature, °F	Hardness RC
B4F-18-5[a]	61.0	10.7	4.76	18.2	4.5	...	0.8	2080	2150	30-33
5H-5Sn[a]	66.0	16.2	7.65	5.9	...	3.5	0.7	2050	2150	40
5H-25[a]	54.7	14.0	5.8	25.0	...	...	...	...	1925	44
7M[b]	69.7	13.7	6.9	8.3	...	...	1.3	...	2100	44
131-2[b]	82.0	8.7	4.2	5.0	...	...	0.5	...	2200	33
131-1[a]	82.3	8.7	1.7	5.0	...	...	2.3	2350	2400	Rb 72

[a] Produced in powder form by atomization.
[b] Produced in shot-cast form.

Table 7—Physical Test Data for Two Alloys Produced as Cast-tensile Bars

Alloy designation	Ultimate tensile strength, psi	Yield strength, psi	Elongation, %	Reduction in area, %	Hardness
131-1	52,000	26,000	28.0	37.5	RB 72
	52,000	26,000	36.0	39.3	
	51,000	32,000	30.0	22.0	
	59,400	32,000	31.0	41.0	
131-2	109,000	87,000	18.0	41.5	RC 33
	101,200	86,000	16.0	33.7	
	107,000	86,000	49.0	61.5	

Alloy Performance

The modified B4F-18-5 alloy showed low hardness, good flow and wetting on stainless steels, Inconel, Haynes No. 25 alloy and pure molybdenum metal. Data on shear strengths at room and at elevated temperatures averaged about 20–50,000 psi, depending on factors such as fit, base metal material and soak time. The shear strength properties were consistent with present available brazing alloys up to 1800° F. Two aircraft engine manufacturers reported braze alloy fillet hardnesses of Rockwell C 26–28 converted from microhardness readings. Further tests indicated "little or no erosion" on Stainless Steel 18–8, Haynes No. 25 and Inconel at 2150° F for periods up to 30 min. Each base alloy reacts differently, and individual wetting and erosion tests would be required at the temperature selected for the brazing operation.

Alloy 5H-5 Sn with 3.5% tin did not show an appreciable lowering of the braze flow temperature as was expected. Some liquation was noted when brazing at 2100 and 2125° F. This alloy was harder and probably less ductile than the other alloys under consideration. Wetting and erosion tests on Haynes 25 alloy at 2200° F indicated comparable characteristics with present silicon-containing braze alloys. It is possible that the choice of 3.5% tin was not high enough to be effective in lowering the liquidus

temperature. All work prior to this had been with at least 5% tin.

Alloy 5H-25 was chosen for additional consideration only because of its ability to braze copper. The alloy flows well at 1900° F and wets the copper surface excellently. No copper joint strengths were obtained; however, joints when peeled failed through the copper. This alloy could be very useful for heat exchanger work requiring higher working temperatures, corrosion resistance and copper-to-stainless surfaces.

Alloy 7M was selected because of its ability to braze larger joint gaps. The addition of 1.3% iron accomplished this purpose. It flowed well at 2100° F, and shear test data on A-286 alloy showed strengths over 30,000 psi at 1000° F.

All of the alloys showed a capability of being brazed in dry ammogas atmospheres as well as dry hydrogen atmospheres. Chromium contents up to 10% do not seem to adversely affect the choice of atmospheres.

Alloys 131-1 and *131-2* were produced as cast tensile bars. The results are given in Table 7. Alloy 131-1 cannot be used due to its high flow temperature. Alloy 131-2 shows high ultimate strength, yield strength and percent elongation. If these same properties can be produced in a "brazed joint" and fillet, then good brazing efficiency can be obtained.

In conclusion, it can be stated that a new alloy system has been developed within which, and by proper alloying optimization, ductile nickel base brazing alloys can be produced.

Acknowledgments

The authors wishes to thank A. Pagel, metallurgist, Ferrotherm Co., who contributed immensely to obtaining the technical data for this program; as well as William Batten, Vanadium Alloy Steel Co., F. Kenneth Iverson, of Cannon-Muskegon Co., and R. L. Probst, of Federal-Mogul Research Laboratories, for their assistance in obtaining the required alloys in cast and in powder form throughout the program when needed.

EUROPEAN WELDING RESEARCH

(*Continued from page 258-s*)

tember 1960 contains the following research articles.

• Thermal diffusion favors the diffusion of dissolved gas from cold to hot areas. Aa a result, hydrogen tends to diffuse from cold base metal to the heat-affected zone during welding. Permeability coefficients are calculated for iron, copper, aluminum, and nickel. The coefficient is two orders higher for iron than for nonferrous metals.

• A study of the temperature distribution in electroslag welding showed that the maximum temperature of the molten weld metal occurred at the slag metal interface and was 3100° F. At 50 v the maximum slag temperature was 3450° F and occurred at a depth of $1^{3}/_{16}$-in.

• The relations among the variables in arcair cutting were graphed and tabulated. As the current on an electrode $^{5}/_{16}$-in. diam was raised from 160 to 340 amp, the metal removal increased from 9 to 24 lb/hr, while the electrode loss increased from 1.0 to 1.5 lb/hr. For $^{1}/_{4}$-in. electrodes maximum metal removal occurred at a travel speed of 20 ipm at all currents from 112 to 340 amp.

• Stainless steel sheet 0.032 to $^{5}/_{64}$ in. thick was welded with $^{1}/_{16}$-in. stainless steel electrodes using a mixed gas of 70–50% CO_2 and 30–50% argon. This gas provided fine-particle transfer at current densities of 40 and 60 amp/mm² on straight and reversed polarity, respectively.

• A cam-actuated flash welder is described for automobile tire rims.

• In surfacing steel with $^{5}/_{64}$-in. steel electrodes (mild steel or 0.74 C) at low currents with or without 56 cps vibration, a flow of water around the arc reduced the absorption of nitrogen and the loss of C, Mn and Si from the electrode.

• Thulium 170 was used for radiography of welds in magnesium, titanium and aluminum up to $^{5}/_{8}$ in. thick. Sensitivity to defects is graphed as a function of sheet thickness.

• Eight research projects at the Bauman Institute in Moscow in 1959 are summarized. One project involved the construction of a machine for recording the temperature-ductility curve of a weld at temperatures from the liquid state to below any hot cracking range. Other projects involved automation of spot and arc welding.

• The magnetic flux process for welding steel without protective gas has been improved. Four fluxes available, two based on lime and fluorspar, another iron oxide and ferromanganese, and a fourth on rutile. All contain 20% iron and are bonded with sodium silicate. A granulator and oven for flux production are described as well as the torch, boom for wire and weld properties.

• Rolls for a sheet mill were surfaced with a mild steel electrode and an alloyed submerged arc flux depositing metal containing 0.7 C, 5.7 Cr, 2.5 Mn, 0.1 T.i, the hardness being 515 Brinell.

• The construction and circuit of a condenser-discharge welder (18 kw) are described.

• A plasma torch has been developed for semi- and full-automatic cutting of aluminum and stainless steel up to $^{5}/_{8}$ and $^{1}/_{2}$ in. thick, respectively.

• The weight ratio of coating to core of three Russian electrodes was found to vary as much as 15% from the average within the limits specified by the manufacturers for outside diameter of coating.

• A CO_2 welder for pipes has been developed with transverse oscillation of the electrode. The pipe is rotated under the welding head.

Svarachnoe Proizvodstvo for August 1960 contains the following articles:

• An oscillographic study of the arcair process showed that the arc moved from side to side as the electrode advanced. At high cutting speeds (43 ipm) there were electrical explosions, that is high peak currents. The pressure of the arc

(*Continued on page 271-s*)

Pressure Vessel Design Requirements in the Future

Purpose of paper sponsored by IIW is to emphasize rational design procedures for pressure vessels and to review information requirements concerning alternative procedures for more economical design of costly vessels

BY W. B. CARLSON

Introduction

For those who are not familiar with the Pressure Vessels Commission of the IIW it may be useful to give a brief description of its current activities. First let it be said that the IIW-PVC is not a code-making body and does not itself aim at drafting mandatory standards. Its purpose is to make available to designers, manufacturers, users and to code-making bodies, the best technical information which can result from international discussion and cooperation in this field. If in a subsequent part of this paper the outlines of possible future codes are presented, this is done on the author's sole responsibility. It is also done in the belief that a forecast of design methods of the future would constitute a guide to the technical and experimental development requirements of today.

The PVC originated at the IIW Paris General Meeting of 1950 as a working group of Commission II: "Arc Welding." At Oxford in 1951 it was transferred, still as a working group, to Commission XV: "Fundamentals of Design and Fabrication for Welding," and at Florence in 1954 it became a full Commission No. XI with the title: "Pressure Vessels, Boilers and Pipe Lines." The word "Boilers" infers only "Boiler Drums," and the Commission concerns itself solely with pressure vessels and pressure parts.

In the course of the ten-year life of this group, design and manufacturing topics have been discussed, the chief of which are indicated in Appendix I. The current subjects under discussion in the Commission are the following:

1. Drumhead shape delimitation.
2. Recommended weld details for pipes.
3. Weld details for deep-penetration electrodes.
4. Nozzle stressing and performance.
5. Proposals for clad and lined vessels.
6. A rational design procedure for pressure vessels.
7. Stress evaluation.
8. Stress relieving.
9. Nondestructive testing.

Where appropriate these studies, as applied to pressure vessels, are pursued in close cooperation with other IIW Commissions dealing with the same subjects in a broader context. For instance, weld details are discussed with Commission XV and stress relieving and nondestructive testing with Commissions X and V, respectively. The objective is to reach an international viewpoint if possible on what is good practice, without committing anyone to its adoption.

The purpose of the present paper is to deal at greater length with Item 6—to draw attention to alternate procedures which might be adopted toward economical design, and to review the information which would be required. While it is probable that the present-day simple forms of design code, based on conventional design stresses, will remain in use for some time to come, particularly for the routine design of vessels for well-known duties, nevertheless this fact does not preclude the formulation of more sophisticated codes intended to bring about the more economical design of very costly vessels where a greater engineering design effort is worthwhile, and to cater for designs and operating conditions which at present fall outside established codes. It is recognized that considerable investigational effort and experience may be needed before some of these proposals can be realized.

Present Code Procedure

Before dealing with proposed revisions of code procedure, we may remind ourselves of the general principles used in most codes of today for the calculation of pressure part scantlings. These may be described with the aid of Table 1. The philosophy of these codes is generally along the following lines.

Material Properties

For the materials for which the code is applicable, the minimum probability values of some or all of the following physical properties are enumerated against temperature: 0.2% proof stress; ultimate tensile strength; creep stress for 1% elongation in, say, 10^5 hr; creep rupture stress for rupture in, say, 1.5×10^5 hr. It is notable that this is a restricted list of physical properties in comparison with those which might affect the performance of a pressure vessel.

Factor of Safety

To the temperature-dependent values of the above physical properties "factors of safety" are applied to reduce them to workable stresses. In practice the factors are usually of the following order:

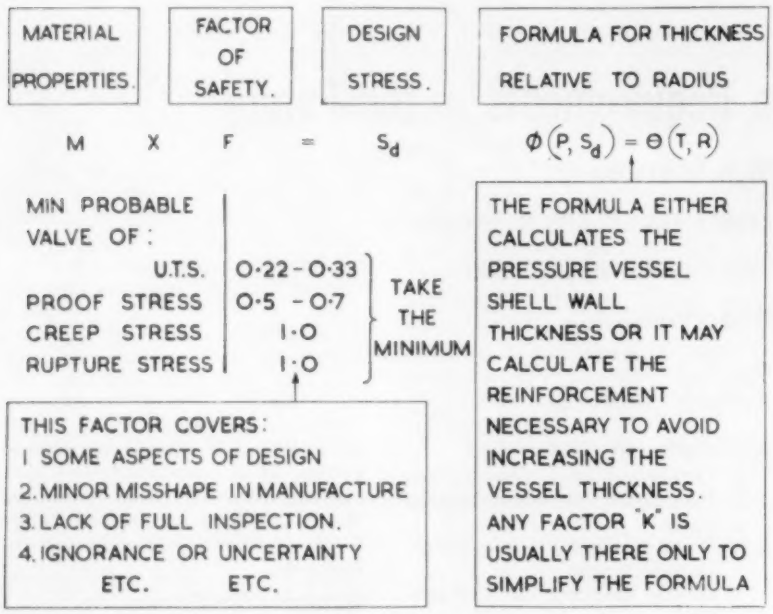
0.22–0.33 on the ultimate tensile strength.
0.50–0.70 on the proof stress.
Up to 1.00 on the creep and rupture stresses.

The factors applied to the creep and rupture stress will of course depend upon the values of the elongation and time associated therewith.

W. B. CARLSON, D. Sc., is Chief Research Engineer, Babcock & Wilcox, Ltd., London, England.

IIW paper presented at AWS 42nd Annual Meeting held in New York, N. Y., Apr. 17–21, 1961.

Table 1—Present Procedure


MATERIAL PROPERTIES.
FACTOR OF SAFETY.
DESIGN STRESS.
FORMULA FOR THICKNESS RELATIVE TO RADIUS
M X F = S_d
$\Phi(P, S_d) = \Theta(T, R)$
MIN PROBABLE VALVE OF :
U.T.S.
PROOF STRESS
CREEP STRESS
RUPTURE STRESS
0·22 - 0·33
0·5 - 0·7
1·0
1·0
TAKE THE MINIMUM
THIS FACTOR COVERS:
1 SOME ASPECTS OF DESIGN
2. MINOR MISSHAPE IN MANUFACTURE
3. LACK OF FULL INSPECTION.
4. IGNORANCE OR UNCERTAINTY
ETC. ETC.
THE FORMULA EITHER CALCULATES THE PRESSURE VESSEL SHELL WALL THICKNESS OR IT MAY CALCULATE THE REINFORCEMENT NECESSARY TO AVOID INCREASING THE VESSEL THICKNESS. ANY FACTOR "K" IS USUALLY THERE ONLY TO SIMPLIFY THE FORMULA

The term "factor of safety" is a misnomer, because this factor's function is to cover a wide variety of possible contingencies as below. Some of these, to put it bluntly, are plain bad features of design which, by use and wont from early days, have become accepted as liable to occur in pressure vessels:

1. Some aspects of design, such as small unreinforced holes and sharp changes in section.
2. Minor misshape is manufacture such as noncircularity, undressed welds and undercutting.
3. Lack of full inspection such as partial X-ray.
4. A feeling of ignorance or uncertainty.

The acceptance of large "factors of safety" for deriving design stress encourages the automatic acceptance of the inevitability of inferior design, which, in the author's view, is a defect which should be eliminated from future codes.

Design Stress

Having applied "factors of safety" to the selected physical properties of the material, the design stress at any temperature is taken as the minimum product at that temperature. This procedure is logical in itself, but it leaves the resultant design stress dependent upon perhaps too few physical properties and too large "factors of safety."

Component Formulas

Most codes present design formulas for particular geometries of component, into which the design stress for the desired temperature is inserted. For some geometries such as drumheads and tube plates, the formula calculates the thickness of the plate forming the component. For others such as nozzles the formula may sometimes give the dimensions of the reinforcement to be added. The formula may be fundamental or empirical, the aim being to cling to extreme simplicity. It may contain an empirical factor K which in most cases merely simplifies an otherwise complex geometric formula, but occasionally may take some cognizance of an environmental condition such as corrosion or entry into the creep range of temperature. The latter functions of K are very limited in their scope in existing codes.

Shortcomings of Present Codes

From the foregoing description it is evident that the relatively simple forms of code in use today tend to take cognizance of too few facts. As a consequence they are inclined to err on the safe side to the detriment of economy. More particularly the position may be described as follows.

The undernoted physical properties, which are of sometime interest to every designer, are among those which are *not* taken into account in determining design stress:

High-strain-fatigue strain range.
Corrosion-fatigue strain range.
Stress-corrosion-cracking stress.
Fast-fracture-initiation stress.
Stress-relaxation creep strain.
Short-term ductility.
Elastic properties.

It is, of course, a fact that materials are chosen bearing certain of these properties in mind; moreover, it may be technically inappropriate to attempt to introduce them into the procedure for determining design stress. However, it is also true that few present-day formulas for the design of components embody any parameter which recognizes the type of failure against which the component is to be designed.

The design stress, as derived by the method described previously under Factor of Safety and Design Stress, is left to cater for all types of failure, which may be liable to occur in different proportions in various vessels. Its success to date is clear proof that it must be highly extravagant in some instances.

Possible Alternative Procedures

Two possible alternatives to present-day code procedures are envisaged. The first could reasonably be negotiated now by code-making bodies. The second is something to which one might look forward in the future, when sufficient data and experience have been systematically accumulated.

The first proposal aims at raising the "tabulated temperature dependent design stress" to the highest value which would be usable in an idealized vessel under ideal operating conditions. The design formula for any particular component would then be devised so as to take due account of both shape-departures and operating-departures from the ideal. Thus the philosophy of this proposal is that one should start with the highest possible design stress and modify it downward as necessary, rather than starting with an excessively safe stress and tolerating the poor design features which it permits.

The second proposal aims at removing the "design-stress" concept altogether from codes, and designing against each contingency of failure by starting from the basic material properties which control such failures. This is an ambitious project for the future, demanding the accumulation of much data and experience which is presently lacking. It is included here mainly with the object of giving some con-

certed general direction to those who are willing and able to pursue investigations in this field.

The foregoing proposals will now be described in greater detail.

First Amended Procedure Proposal

Vessels for the same duty are thinner in some countries than in others, largely because more favorable "factors of safety" are used in converting physical properties into design stresses. In other words good field experience has been followed by larger or more frequent adjustments of these arbitrary and empirical factors.

Another, and seemingly superior, approach to the problem would be to establish the upper limit for the design stress under ideal conditions, and to work backward from this for each departure from the ideal. To this end suppose we define an Idealized Pressure Containment Project as being one in which: (1) the vessel is comprised of one pure geometric shape, such as a thin sphere or an infinitely long thin cylinder, having only pure membrane stressing with no deliberate or accidental stress intensifications, and (2) the conditions of operation comprise only steady internal pressure at constant temperature, with no corrosive media present and no limitations on elastic inflation with pressure. Then, under these ideal conditions, there would be no reason why the membrane stress should not be 99% of a suitable minimum probability value of the yield, or creep, or rupture stress of the material had a reasonable ratio of yield to ultimate tensile strength so as to ensure an adequate margin between yield and plastic instability followed by bursting. Thus the above mentioned minimum probability value could become the basic design stress used in the first amended procedure code. The general philosophy of such a code would be that illustrated in Table 2.

Design Stress

The design stress at any temperature would be *equal* to the lowest of the minimum probability values of the 0.2% proof stress; the creep stress for 1% elongation in, say 10^5 hr, and the creep-rupture stress for rupture in, say 1.5×10^5 hr. There would also be a limit on the maximum proportion of proof stress to ultimate tensile strength. There would be no "factors of safety" standing between the above physical properties and the design stress.

Component Formulas

The formulas for calculating component wall thickness or reinforcement would take account of three things:

1. The presence and distribution of stress and/or strain intensifications due to the *designed* shape-departure of the component from pure thin sphere or cylinder.

2. The possibility of there developing in the component modes of failure other than *uniform full-wall-thickness* yield.

3. The presence of manufacturing tolerances which might have appreciable effect on the stress system and the performance of the component.

The first two of these aspects would be catered for as follows. The component formulas would recognize component shape and loading. They would also recognize an approximate general relationship between the design stress and the specified mode of duty failure against which the component is to be designed, by the use of empirical factors K in the formulas.

The third aspect would be catered for by the application of a manufacturing departure factor d where appropriate.

This first amended proposal would constitute a major step toward breaking away from the stultifying effects of basing the designs of all components on a design stress incorporating a large arbitrary "factor of safety." The detailed implimentation of this proposal for component design would require to be worked out, but the general lines on which it might operate are suggested in Appendix II.

This proposal, like any other which may be made in the absence of complete technical information on the behavior of pressure vessels, is subject to the criticism that it must inevitably depend on the use of certain practically determined factors. Its virtue is claimed to be in the use of separately determined factors in separate situations, thus bringing individual component scantlings nearer to their minimum permissible values.

Second Amended Procedure Proposal

This proposal recognizes the fact that it is illogical to base design procedures aimed against a variety of failure contingencies on the use of a single "design stress." Design against fatigue, stress corrosion, brittle fracture or against elastic deformation, all demand the use of material properties which are not

Table 2—First Amended Procedure Proposal

MATERIAL PROPERTIES	DESIGN STRESS	FORMULA FOR THICKNESS RELATIVE TO RADIUS
	$M = S_d$	$\Phi\ (K, d, P, S_d) - \Theta\ (T, R)$
MIN. PROBABLE VALVE OF PROOF STRESS CREEP STRESS RUPTURE STRESS	THE DESIGN STRESS IS THAT STRESS WHICH MIGHT BE APPLIED IN CONDITIONS OF IDEALISED MEMBRANE STRESSING UNDER STEADY LOAD AND TEMPERATURE WITH NO COMPLICATIONS.	THE FORMULA CALCULATES SHELL THICKNESS OR THE THICKNESS FOR A REINFORCEMENT, TAKING ACCOUNT OF THE APPROPRIATE CRITICAL CRITERION OF FAILURE WITH THE AID OF A FACTOR 'K'. THE FORMULA ALSO ALLOWS FOR VARYING TOLERANCES ON THE COMPONENT GEOMETRY THROUGH A MANFACTURING DEPARTURE FACTOR 'd'.

Table 3—Second Amended Procedure Proposal

MATERIAL PROPERTIES.	FORMULA FOR THICKNESS RELATIVE TO RADIUS.
M	$\Phi\ d, P, M) - \Theta\ (T, R)$
MINIMUM OR MAXIMUM PROBABLE VALUES OF ALL STRESS PROPERTIES, AND ALL ELASTIC AND PLASTIC STRAIN PROPERTIES, ARE TABULATED AGAINST TEMPERATURE AND USED DIRECTLY FOR SCANTLING DESIGN.	THE FORMULA USES THE APPROPRIATE PHYSICAL PROPERTY 'M' DIRECTLY SO AS TO DESIGN AGAINST THE CRITICAL CRITERION OF FAILURE WHICH IS OPERATIVE. IT THUS CALCULATES SHELL THICKNESS OR REINFORCEMENT WITHOUT THE NEED FOR A FACTOR OTHER THAN THE MANUFACTURING DEPARTURE FACTOR 'd'.

taken into direct account in the derivation of a single "design stress." They may be allowed for indirectly by the method of the "First Amended Procedure" as suggested in Appendix II. A superior method would be to accumulate adequate material property data, and to use this directly in formulas designed to cater for each failure contingency or criterion.

The philosophy of the second proposal is summarized in Table 3, and a list of failure contingencies, critical criteria and material properties is given in Table 4, which may be regarded as fairly comprehensive.

Much data is needed to enable this proposal to be put into effect. Nevertheless it is pleasing to be able to report that the IIW Pressure Vessels Commission has made a systematic start on the problem. Toward this end it invited the delegations of several countries to each write a first draft thesis on designing against one of the Table 4 failure contingencies. So far initial theses have been forthcoming as follows:

Brittle fracture	UK
High strain fatigue	USA
Stress corrosion	France
Excessive plastic deformation	Netherlands

The objective has been to pinpoint the state of the art in these fields as applied to pressure vessels. Each thesis should itself form a guide to the work still required, and should be periodically brought up to date. It is not claimed that the approach is novel, but it is aimed at being fairly comprehensive.

Conclusion

It is claimed that most of the conventional pressure vessel scantling design codes of today are both unnecessarily restrictive and insufficiently comprehensive in their coverage. They are restrictive because all parts of the vessel are designed from one design stress which is factored to cover the worst features which might be met in any vessel. They are insufficiently comprehensive because some forms of failure are ignored.

To overcome these disabilities a two-stage program is proposed. The first stage could be undertaken now, and would be to revise the basis of the design stress and the methods of design therefrom so as to encourage good design and discourage bad. The second stage requires more comprehensive data than we have now, and would comprise design direct from physical data rather than design stress.

Acknowledgments

The author wishes to thank the management of Babcock & Wilcox Ltd., London, for making it possible for him to present this paper in New York. He also wishes to thank many friends and colleagues for their encouragement and help, and in particular A. C. Mackenzie and J. Spence of the Babcock & Wilcox Research Station in Renfrew, Scotland.

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APPENDIX I

The principal subjects which have been discussed by the IIW Pressure Vessels Commission XI during the ten years of its existence as a group are the following:

Design Topics

Tabulation of materials and their properties.
The design of drumheads.
The design of flanges.
The compilation of recommended weld details.
Butt weld surface finish and weld efficiency.
Allowable stress and a rational design procedure.
Out-of-roundness of cylindrical shells.

Manufacturing Topics

Stress relief.
Nondestructive testing.
The pressure test.

It will be realized that in the formative years of an international organization, with at times a changing representation from member countries, much effort had to be devoted toward finding common ground and establishing methods of achieving progress. Little can be achieved at one large meeting a year,

Table 4—Failure Contingencies and Corresponding Critical Criteria

FAILURE CONTINGENCY	CRITICAL CRITERIA
1. EXCESSIVE PLASTIC DEFORMATION a SHORT-TERM (ON LOADING) 1. UNIFORM F-W-T DEF. 2. NON-UNIFORM DEF. b LONG-TERM (CREEP) 1. UNIFORM F-W-T DEF. 2. NON-UNIFORM DEF.	FIRST YIELD. CHANGE OF SHAPE PER SE. TROUBLE AT NON-INTEGRAL JOINTS. LOW-ELONGATION CRACKING. PLASTIC INSTABILITY.
2. EXCESSIVE ELASTIC DEFORMATION	CHANGE OF SHAPE PER SE. MALDISTRIBUTION OF LOADS. TROUBLE AT NON-INTEGRAL JOINTS. ELASTIC INSTABILITY.
3. HIGH-STRAIN FATIGUE.	FATIGUE CRACKING.
4. CORROSION FATIGUE.	CORROSION FATIGUE CRACKING.
5. STRESS CORROSION.	STRESS CORROSION CRACKING.
6. BRITTLE FRACTURE.	LOW-STRESS FRACTURE INITIATION

MATERIAL PROPERTIES INVOKED.

1. PROOF STRESS, ELONGATION, R.A., CREEP STRESS, CREEP & RELAXATION STRAIN, RUPTURE STRESS & DUCTILITY.
2. MODULUS OF ELASTICITY, POISSONS RATIO.
3. FATIGUE STRAIN RANGE FOR FAILURE IN 'N' CYCLES.
4. CORROSION FATIGUE RANGE FOR FAILURE IN N CYCLES.
5. STRESS CORROSION STRESS FOR CRACKING IN 't' HRS.
6. LOW-STRESS FRACTURE INITIATION CONDITIONS.

Table 5—Formulas for Internal Pressure Loading

DESIGN AGAINST	THIN CYLINDER (OPEN ENDED)	THIN SPHERE	THICK CYLINDER (OPEN ENDED)	DRUMHEAD ON THIN CYLINDER	NOZZLE ON THIN SPHERE
EXCESSIVE SHORT-TERM PLASTIC DEFORMATION	$\frac{T}{R} = \frac{P}{S_d}$	$\frac{T}{R} = \frac{P}{2S_d}$	$\frac{T}{R} = \frac{P}{S_d}$	$\frac{T}{R} = \frac{(SIF)}{1.7} \cdot \frac{P}{S_d} = \frac{(SIF)}{K} \cdot \frac{P}{S_d}$	$\frac{T}{R} = \frac{(SIF)}{1.7} \cdot \frac{P}{2S_d} = \frac{(SIF)}{K} \cdot \frac{P}{2S_d}$
EXCESSIVE LONG-TERM CREEP	$\frac{T}{R} = \frac{P}{S_d}$	$\frac{T}{R} = \frac{P}{2S_d}$	$\frac{T}{R} = \frac{P}{S_d}$	?	?
EXCESSIVE ELASTIC DEFORMATION	$\frac{T}{R} = \left(\frac{S_d}{E\epsilon}\right)\frac{P}{S_d} = \frac{1}{K} \cdot \frac{P}{S_d}$	$\frac{T}{R} = \left(\frac{S_d}{E\epsilon}\right)\frac{P}{2S_d} = \frac{1}{K} \cdot \frac{P}{2S_d}$	$\phi\left(\frac{R_0}{R}\right)\frac{S_d}{E\epsilon}\frac{P}{S_d} = \frac{1}{K} \cdot \frac{P}{S_d}$	GALLETLY	?
HIGH-STRAIN FATIGUE	$\frac{T}{R} = \left(\frac{S_d}{S_f}\right)\frac{P}{S_d} = \frac{1}{K} \cdot \frac{P}{S_d}$	$\frac{T}{R} = \left(\frac{S_d}{S_f}\right)\frac{P}{2S_d} = \frac{1}{K} \cdot \frac{P}{2S_d}$	MORRISON CROSSLAND AND PARRY	$\frac{T}{R} = \frac{(SIF)}{K}\left(\frac{S_d}{S_f}\right)\frac{P}{S_d} = \frac{(SIF)}{K} \cdot \frac{P}{S_d}$	$\frac{T}{R} = \frac{(SIF)}{K}\left(\frac{S_d}{S_f}\right)\frac{P}{2S_d} = \frac{(SIF)}{K} \cdot \frac{P}{2S_d}$

and smaller groups had to be formed who were willing to work individually and collectively on detailed subjects. Thus only some of the topics mentioned have made appreciable headway. Whenever practicable, the Commission has recommended to the Governing Council of the IIW the publication of documents in the national technical press of member countries, or their circulation in other suitable forms. The following is a selected list of statements:

1955/1: Reply to PVRC questionnaire in connection with their investigation of the effects of fabrication operations on materials for high temperature service.

1955/3: Recommendation that a condensed version of Commission XI's report on the calculation of pressure vessels be sent to ISO/-TC.11.

1955/4: Statement of the problem of stress relieving in relation to brittle fracture in pressure vessels.

1956/1: Recommendation that document entitled "Recommended Welded Connections (tentative)" be passed to ISO/TC.11 and published for comment in member countries.

1956/2: Similar recommendation on "Pressure Vessel Design (tentative)."

1957/1: Recommendation that a working group on "Stress Relieving in Pressure Vessels" be formed to develop Doc. XI-9-57.

1957/2: Recommendations that a working group on "Non-destructive Testing for Flaws in Pressure Vessels" be formed to develop Docs. XI-10-57 and XI-17-57.

1958/1: Recommendation that Doc. XI - 26 - 58, "Recommended Welded Connections for Pressure Vessels" be published by the IIW subject to approval by member countries.

1958/2: Recommendation that Doc. XI-21-58 "A Rational Design Procedure for Pressure Vessels" be published in member countries.

1959/1: Recommendation that Doc. XI-33-59 "Pressure Vessel Brittle Fracture and Information Required to Design Against It" be published for comment in member countries.

1960/1: Recommendation that Doc. XI-45-60 "On the Desirability of Stress Relieving in Welded Pressure Vessels" be published for comment in member countries.

1960/2: Request to Commission V that they extend their study of radiographic image quality to steel thicknesses up to 8 in.

1960/3: Recommendation that Doc. XI-43-60, "Electrochemical Investigation of Corrosion Fatigue of Steel and Methods of Protection," be transmitted to Commission XIII.

1960/4: Recommendation that Doc. XI-53-60, "Efficient Methods and Rational Organisation of Welding in the Construction of High Pressure Pipe Lines," form the theme of a colloquium, or a series of lectures, or of a public session.

The foregoing makes no reference to papers received, discussed and referred within the Commission.

APPENDIX II

Scantling Calculations on First Amended Procedure Proposal

Starting with the "Idealized Pressure Containment Project" defined under "First Amended Procedure Proposed" in the paper, the methods of calculating a thin sphere and an infinitely long thin cylinder, respectively, would be:

$$\frac{T}{R} = \frac{P}{2S_d} \qquad (1)$$

and:

$$\frac{T}{R} = \frac{P}{S_d} \qquad (2)$$

respectively, where:

T = thickness.
R = radius.
P = pressure.
S_d = design stress on the first amended procedure basis.

Departures from the ideal may be of three general forms as already explained, namely:

1. In the *designed* shape, such as making the vessel thick; putting an end closure on a cylinder: putting a hole or a nozzle into the vessel, etc.
2. Catering for failure other than by *uniform full-wall thickness* yield, such as putting a limit on elastic strain; putting a limit on short-term plastic deformation; or avoiding high-strain fatigue, corrosion fatigue, corrosion fatigue, stress corrosion, brittle fracture, etc.
3. Allowing for manufacturing tolerances.

To cater for any of these departures from the ideal, the generalized design equation for sphere and cylinder may be written:

$$\theta(T, R) = \phi(K, d, P, S_d) \qquad (3)$$

where:

θ, ϕ = functions catering for the intended forms of geometry.
K = a factor catering for various forms of failure against which the vessel is to be designed.
d = a departure factor catering for the fact that manufacturing tolerances permit components to depart from the designed shape.

One of the complications of pressure vessel design is that the above forms of departure from the ideal cannot each be treated separately in generalized form. By this it is meant that, generally speaking, it is necessary to specify the particular geometry before considering the effects of the type of failure against which the design process is to guard. Thus it is now necessary to consider particular geometries in order to illustrate the use of K in designing against particular failure contingencies. It is also necessary to bear in mind that the "First Amended Procedure Proposal," with which we are presently concerned, is one which is still based on the use of a "design stress" as the primary starting point in the design process. All formulas must, therefore, incorporate this quantity.

In order to simplify the following illustrations, the factor d will be assumed unity. This in no way prevents its being given an appropriate value in a practical case, because it is a straight multiplier to factor K.

Starting with the most usual simple geometry let us consider the following.

(a) Thin Cylinders (Open Ended)

We have already noted that under idealized pressure containment conditions, design would proceed in accordance with eq 2. If, however, a limit were imposed on the maximum elastic strain permitted in the vessel so as to avoid, for example, distortion of a mechanical joint, then:

$$\frac{PR}{T} = E\epsilon$$

where

E = Young's modulus and ϵ = strain.

$$\frac{T}{R} = \frac{P}{E\epsilon} = \left(\frac{S_d}{E\epsilon}\right)\frac{P}{S_d} = \frac{I}{K}\cdot\frac{P}{S_d} \qquad (4)$$

Thus vessels normally designed to a stress of say 30,000 psi (amended basis), but requiring a strain limitation of say 0.00025 in./in., would require $K = 0.25$, and the design formula would become:

$$\frac{T}{R} = \frac{1}{0.25}\frac{P}{S_d} \qquad (5)$$

making the vessel four times thicker than purely stress considerations would demand.

This simple example illustrates one of the absurdities of designing solely from a design stress, and one of the reasons why we should ultimately aim at the "Second Amended Procedure Proposal."

Suppose next that the thin cylinder is required to withstand an appreciable number of pressure fatigue cycles, and that the appropriate limiting fatigue stress range is S_f. The direct approach would be to use:

$$\frac{T}{R} = \frac{P}{S_f} \qquad (6)$$

but under the "First Amended Procedure" this equation would be written:

$$\frac{T}{R} = \left(\frac{S_d}{S_f}\right)\frac{P}{S_d} = \frac{I}{K}\cdot\frac{P}{S_d} \qquad (7)$$

In other words the fatigue criterion would be related to ideal design conditions by means of a factor K, which might have been determined on a related component or specimen at design temperature but not necessarily on the particular component being currently designed.

(b) Thick Cylinders (Open Ended)

These represent a departure from the ideal in respect of geometry, but if the form of failure against which design is to proceed is full-wall-thickness yielding on either short or long term, then eq 2 with R interpreted as the mean radius can be shown to be adequate.

If a limit is to be imposed on maximum elastic strain, then of course elastic equations must be used:

$$P\left[\frac{R_0^3 + R_i^3}{R_0^3 - R_i^3} + \nu\right] = E\epsilon_i$$

$$P\left[\frac{2R_i^3}{R_0^3 - R_i^2}\right] = E\epsilon_0$$

where R_0 = outside radius and R_i = inside radius; whence:

$$\left[\frac{R_0^3 + R_i^3}{R_0^3 - R_i^3} + \nu\right]^{-1} = \frac{P}{E\epsilon_i} = \left(\frac{S_d}{E\epsilon_i}\right)\frac{P}{S_d} = \frac{I}{K}\cdot\frac{P}{S_d} \qquad (8)$$

$$\left[\frac{2R_i^3}{R_0^3 - R_i^3}\right]^{-1} = \left(\frac{S_d}{E\epsilon_0}\right)\frac{P}{S_d} = \frac{I}{K}\cdot\frac{P}{S_d} \qquad (9)$$

These equations are directly comparable with eq (4) which represents the thin cylinder case.

To design a thick cylinder against fatigue is not at the moment a straightforward case[1] and is here left to the specialist.

(c) Drumhead on Thin Cylinder

This combination is a departure from the ideal in respect of geometry, with possibly the single exception of the hemispherical head of half the thickness of the shell. Even in this case there is a thickness transition. In general there are incompatibility forces and moments between cylinder and head, which make it impracticable to design against uniform full-wall-thickness yielding. Thus there must also be a departure from the deal in respect of the design criterion, even for design against excessive short-term plastic deformation.

The bulk of both theoretical and experimental data for drumheads is concerned with elastic stress distributions. Very little data exists for drumheads under elastic-plastic or fully plastic conditions. Perhaps the most promising method for design of very thin drumheads against excessive short-term plastic deformation is to base on the limit pressure obtained by the methods of limit analysis. Shield and Drucker[2] have obtained the limit pressures for ASME standard heads in the range T/R = 0.008 to 0.028 for the particular case of crown radius equal to cylinder radius. Their results can be used for the design of such ASME heads against excessive short-term plastic deformation, and could usefully be extended to other drumhead geometries.

If, however, available elastic solutions have to be used as an intermediate measure for design against excessive short-term plastic deformation, then it is well-known that it would, in general, be too conservative to design against the onset of theoretical yield. Instead some advantage can be claimed for the constrained nature of the system and the well-known redistribution of stress after the first application of pressure to the vessel. According to simple theory this should permit the maximum stress to reach twice the design stress S_d (amended basis), but it is more usual to use $1 < K < 2$ depending on the constraint of the system and the local yield behavior. Thus:

$$\frac{T}{R} = \frac{(SIF)}{K}\cdot\frac{P}{S_d} = \frac{(SIF)\,P}{1.7\,S_d} \qquad (10)$$

where:

(SIF) = elastic stress intensification factor of the head referred to the hoop stress in the cylinder.

R = cylinder radius.

If a limit is to be imposed on maximum elastic strain, for instance to limit deformation at a manhole opening, equations on the same principles as eq 4 may be formulated.

If necessary to design against a limiting fatigue stress range of S_f then the equation becomes:

$$\frac{T}{R} = (SIF)\left(\frac{S_d}{S_f}\cdot\frac{P}{S_d}\right) = \frac{(SIF)}{K}\,\frac{P}{S_d} \qquad (11)$$

on similar lines to eq 7.

(d) Nozzle in Thin Sphere

Like the drumhead dealt with under Section (c) this combination is a departure from the ideal in respect of geometry. This being so, it is also impracticable to design the combination against uniform full-wall-thickness yielding, and thus there is also a departure in respect of the design criterion. In point of fact practicable nozzle-in-shell design today still rests on the use of elastic solutions. Thus to design against:

1. Excessive short-term plastic deformation, eq 10 is used.
2. Excessive elastic deformation, an equation on the same principle as eq 4 is used.
3. Fatigue, eq 11 is used.

In all cases T/R refers to the main shell, and the stress intensification factor responds to the other key dimensions and is related to the undisturbed shell stress—also where K depends on the degree of constraint and local yield behavior of the system, and may reach 1.7 for nozzles in spheres, subject to checking for very thin spheres.

Good elastic solutions are available for radial nozzles in spheres, and it is possible that many cases of nonradial nozzles in spheres, and also nozzles in cylinders, can be treated by adjustment thereto.

Sufficient has been given above to illustrate the principles of the "First Amended Procedure Proposal." These are summarized in Table 5. It is the province of code-making bodies to decide whether these proposals should be detailed and carried into effect. Sample calculations on a nozzle problem are given in Appendix III.

APPENDIX III

Illustrative Example on First Amended Procedure Proposal

Consider the design of a thin spherical vessel having a radial cylindrical nozzle to comply with the following requirements:

Sphere ID, in.	800
Nozzle ID, in	24
Design pressure, psig	80
Design temperature, ° F	20
Full pressure cycles in life, max	10,000

Noncorrosive liquid.
Welded nozzle, flush on inner surface.
No added compensating pads.
Shape tolerance within ±0.5%.
Full radiography and stress relief.

Assume the material to be SA-201-A:

C, %	0.20–0.35
Si, %	0.15–0.30
Mn, %	0.80
P, %, max	0.035
S, %, max	0.04
Design stress at 20° F, psig	13,750
Yield stress at 20° F, psi	29,900

Present Procedure (ASME 1959 Unfired Pressure Vessel Code)

$$T_s = \frac{PR_s}{2S_dE - 0.2P}$$

$$= \frac{80 \times 400}{(2 \times 13{,}750 \times 1) - (0.2 \times 80)}$$

$$= 1.16 \text{ in.}$$

$$T_n = \frac{PR_n}{S_d E - 0.6P}$$

$$= \frac{80 \times 12}{(13{,}750 \times 1) - (0.6 \times 80)}$$

$$= 0.07 \text{ in.}$$

Total cross-sectional area of compensation required to be added as first approximation:

$$= 1.16\,(24 + 2 \times 0.07) = 28 \text{ in.}^2$$

From these basic quantities and the calculations for A_1 and A_2 it is found that the following typical combinations of thickness satisfy the code requirements:

T_n/T_s	1.5	1.0	0.5
T_s, in.	1.66	1.75	2.25
T_n, in.	2.50	1.75	1.13

First Amended Procedure Proposal

Under the design conditions postulated, it can readily be shown that the most likely general failure contingency would be excessive short-term plastic deformation. Hence:

$$T_s = \frac{PR_s}{2S_d}$$

$$= \frac{80 \times 400}{2 \times 29{,}900}$$

$$= 0.535 \text{ in.}$$

$$T_n = \frac{PR_n}{S_d}$$

$$= \frac{80 \times 12}{29{,}900}$$

$$= 0.032 \text{ in.}$$

If these basic dimensions were used as such, then from Rose and Thompson[4] the circumferential stress intensification factor at the nozzle bore would be obtained as follows:

$$\text{Replacement factor } y = \frac{0.39 \times 0.032}{0.535}$$

$$\left(\frac{0.032}{12}\right)^{1/2}$$

$$= 0.001$$

$$\frac{R_s}{T_s} = \frac{400}{0.535} = 750$$

$$\frac{R_n}{R_s} = \frac{12}{400} = 0.03$$

From Fig. 1.5 of that paper it is seen that the maximum stress intensification factor in the shell will be $(SIF) = >3.0$, that is, greater than 1.7.

Thus the shell thickness of 0.535 in. would not comply with the formula:

$$\frac{T_s}{R_s} = \frac{(SIF)}{1.7} \cdot \frac{P}{2S_d}$$

for nozzles in thin spheres when designing against excessive short-term plastic deformation.

Repeating the stress intensification factor calculation using new trial values as follows:

$$T_s = 0.875 \text{ in.}$$

$$T_n = 0.5T_s = 0.438 \text{ in.}$$

it is found that $(SIF) = 2.7$. Checking back:

$$T_s = \frac{2.7}{1.7} \cdot \frac{80 \times 400}{2 \times 29{,}900} = 0.85 \text{ in.}$$

This value could be adjusted up to, say, 0.86 in. for complete balance, but in practice the external fillet weld might provide the remaining reinforcement needed. The following typical combinations of thickness satisfy the first amended procedure theoretical calculation:

T_n/T_s	1.5	1.0	0.5
T_s, in.	0.63	0.70	0.86
T_n, in.	0.95	0.70	0.43

These values show a surprising contrast with those obtained from the code, particularly when it is remembered that the amended procedure formula uses the relatively unfavorable factor 1.7 in place of the theoretical value of 2.0 for plastic stress adjustment.

However, it must be recalled that no factor d for manufacturing shape departure from the ideal has been incorporated. This factor should be included in the formula as follows:

$$\frac{T_s}{R_s} = d \cdot \frac{(SIF)}{1.7} \cdot \frac{P}{2S_d}$$

as d is a multiplier to the stress intensification factor.

A typical maximum out-of-roundness of $\pm 0.4\%$ in a thin cylindrical shell would make $d = 1.5$. Thus the above thicknesses could reasonably be increased by 50%, giving the following *practical* values from the first amended procedure:

T_n/T_s	1.5	1.0	0.5
T_s, in.	0.95	1.05	1.29
T_n, in.	1.43	1.05	0.65

These values still show a remarkable reduction on the code thicknesses.

Checking the above conclusions for design against high strain fatigue, it has been found in many experiments that the measured maximum strain range to produce failure in 100,000 cycles has to be of the order of 0.2%. This corresponds to a notional elastic fatigue stress of:

$$S_f = 30 \times 10_6 \times 0.002$$

$$= 60{,}000 \text{ psi}$$

$$\therefore K = \frac{60{,}000}{29{,}000} = 2.0$$

which, when substituted into the formula:

$$\frac{T_s}{R_s} = \frac{(SIF)}{K} \cdot \frac{P}{2S_d}$$

will give a thinner shell than when $K = 1.7$.

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(*Continued from page 264-s*)

moved from side to side as the electrode advanced. At high cutting speeds (43 ipm) there were electrical explosions, that is high peak currents. The pressure of the arc was measured and was found to be higher than the electromagnetic force on straight polarity with steel and cast iron but lower on reverse polarity. For example, at 200 amp the electromagnetic force was 800 mg, the arc force on reverse polarity was 150 mg, but on straight polarity it was 1350 mg.

• The strength of the bond achieved by hot rolling two bars of different steels together was found to increase as the rolling temperature and percentage of reduction were increased. For example, for the pair mild steel and 17% Cr–2% Ni steel at 2000° F and 60% reduction the joint strength was 53,000 psi.

• An arc strike ($^1/_8$-in. electrode, 100 amp) was made on specimens of eight structural steels $^5/_{16}$ in. thick, $^1/_2$ in. wide. The specimens were tested in an impact machine, the arc

(*Continued on page 288-s*)

Pressure Vessel Analysis of Submarine Hulls

Basic Information on submarine hull design as developed over the past 10 years is presented because of its significance in pressure vessel technology

BY EDWARD WENK, JR.

PREFACE. Submarine hulls now represent the largest welded pressure vessels ever constructed. The *Triton* displaces 7750 tons; Polaris Fleet Ballistic Missile subs, the *George Washington* and *Ethan Allan*, displaces 6710 and 7890 tons respectively. Entirely apart from their great size, the hulls represent unique accomplishments in structural design and welding technology. Their low 1.5–2.0 safety margin dramatically illustrates the precision in structural analysis and the care that must be exercised in assembly. Future demands in submarine warfare, particularly with regard to increased operating depth, suggest that the contemporary submarine will undergo even further evolution. Depths of operation 10–20 times those now afforded submarines in the fleet have been forecast.

The latest set of problems concerned with hull technology focuses attention on the need for an enhanced program of research and development for new materials, for their welding or other modes of assembly.

This particular paper is intended to correlate, summarize and interpret information from a variety of reports and open source literature concerned with the pressure vessel analysis of submarine hulls. The basic mechanics of vessels under external hydrostatic pressure are discussed, together with approaches to a minimum weight design. Emphasis is placed on principles rather than procedures. Included is an extensive bibliography that may assist the interested reader in pursuing details further.

Introduction

The strength analysis of submarines represents one of the most interesting areas to challenge the skill of the structural designer. Yet, only the slightest trace of rational theory, collateral test results, or techniques of application has found publication in the open literature. In great measure, this gap in information is a consequence of there being so relatively few engineers and scientists engaged in this activity, of the limited market for results, the vicissitudes of support for research and development, and—finally—considerations of military security. Yet, basic information developed for submarine hull design has implicitly wide engineering application. Of all the fields that could potentially benefit by progress in submarine hull science (and parenthetically the one from which numerous design concepts have been borrowed), that of pressure vessel technology is the most significant.

Submarine hulls are, in fact, vessels subjected to external hydrostatic pressure. Although military use may dictate such unique design criteria as resistance to enemy attack, other criteria such as low cost, ease of construction, maintenance and repair, and—above all—reliability suggest that submarines and commercial pressure vessels have much in common.

This resemblance weakens, however, when evaluating the relative significance of structural weight. It disappears completely when comparing the concomitant safety factors. With the submarine, provision of lightweight structure is far more critical than in pressure vessel practice. If submarine hulls were indeed designed with a conventional safety factor of four, the boat might well sink at launching, never to operate satisfactorily—defeated in the necessary compromises of carrying requisite payload, of manifesting adequate strength for running at the specified depths and of preserving adequate buoyancy to permit the option of surface vs. submerged operation.

The safety factor for submarines is defined as the ratio of the collapse depth (predicted from computations and confirmed by model tests) to the specified operating depth. In recent years, it has been shrunk to the value of 1.50–2.0.[1] Such steps have been taken in full cognizance of the almost certain loss of life, as well as of ship, in the event of structural failure. Under such circumstances and other things being equal, a high safety factor would have been selected. In that event, however, the corresponding weight of hull structure becomes unacceptable. Such an obvious but painful dilemma between contradictory requirements for hull weight has been resolved by precision in design—a precision emanating from an experience — deduced methodology, from the meticulous proportioning of structure, and particularly from comprehensive research programs of the U. S. Navy. Proof of this high accuracy in strength prediction has been confirmed by tests to destruction of small as well as large scale models that have led to unqualified confidence in hull strength by designers and naval crews alike. In never having lost a U. S. submarine in peacetime from structural weakness (wartime losses being undiagnosable), the submarine service may well claim a record of safety in terms of passenger miles per death that compares favorably with statistics of pedestrian hazards at Times Square.

In some measure, it was this favorable history that temporarily stifled advances in submarine structures. A busy interval of submarine model testing had evolved between 1929 and 1935, particularly to confirm analysis by German designers of World War I submarines. Incidentally, much of the U. S. design procedures then crystallized from an exceedingly wholesome and free exchange of information be-

EDWARD WENK, JR., is Senior Specialist in Science and Technology, Legislative Reference Service, Library of Congress, Washington, D. C.

This paper has been reviewed by the Navy Department for security material and has been released as unclassified. The opinions expressed therein, however, are solely those of the author and do not necessarily represent the views of the Navy.

tween the Navy and the ASME-Pressure Vessel Committees as ASME publications of Windenburg, Trilling, and Saunders clearly testified.[2-4] From 1936 to 1950, virtually no research or development was undertaken by the U. S. Navy. The notion then prevailing was that past success in design had proved completeness of knowledge in the field. While new demands on structure from extension in operating depth evolved after 1936, it was based on available technology. No need was expressed until recently for review or extension of fundamentals or design concepts that then had become frozen.

Submarine Analysis Since 1950

The resurgence of submarine analysis in 1950 developed without new or more demanding operational requirements; no compelling sense of urgency arose for more efficient structure; no "barn door closing" was stimulated by a structural failure. Moreover, the political, economic and research climate of 1949–50 was characterized by contracted defense budgets. A zealous pursuit of new knowledge had not yet been polarized by the Korean War nor the Sputnik impact of Soviet science and technology. Despite this lack of stimulation, a searching re-examination of the then prevailing state of the art was initiated by a handful of researchers, naval architects and submarine operators, based on the conviction that submarines would play an increasingly vital role in our military posture. A modest program of research was undertaken to determine whether the technical knowledge then available was adequate to satisfy the yet unspecified but anticipated demands that would be placed upon it. Almost immediately, significant areas for study were uncovered that gave promise of improved structural efficiency, but solicitation of support for expanded theoretical and experimental analysis of thin elastic shells did not find widespread or enthusiastic response. Yet, a start was made in developing program, staff and facilities.

This quest for a more rational approach to hull design made possible solution of a new problem first posed in 1952 of the cone-cylinder junctures, initially for the nuclear-powered *U.S.S. Nautilus*. A relevant body of knowledge had been developed by the Pressure Vessel Research Committee, and their papers—especially those of W. R. Burrows—found instant application. Engineering extension and experimental collaboration by the Navy followed. Almost simultaneously the need arose for enhanced structural theory to support effective use of higher yield strength steels in the *U.S.S. Albacore* and all later submarines. Subsequently came additional unexpected requirements for large-diameter fleet ballistic missile submarine hulls, with critical problems induced by multiple openings for missile hangers. Finally with the advent of nuclear power, unlimited high-speed submerged operation could be attended by an enormously increased number of dives. Problems then arose because the character of service loading was altered from hydrostatic to cyclic.

Looking to the future, yet another new impetus to this spirit of inquiry has been the recent spur of increased operating depth. Interest has emerged from two separate but related sources—the first, scientific, and the second, military. Regarding ocean science, oceanographers recently developed a widespread understanding that with 71% of the earth's surface covered by water, there is great need to explore the ocean by measurements all the way to and including the bottom. Deep diving manned submersibles have thus emerged as a significant tool to explore and, in many cases, to replace less satisfactory techniques that depend on measurements made automatically and remotely by unmanned instruments.

With regard to the military significance of depth, it must be recalled that the submarine gains its combat effectiveness through the process of concealment beneath the surface. While the first 50 ft. of water covering the hull furnish an envelope of protection opaque to visible search and electromagnetic radiation, there is increasing evidence that extended service depth is desirable for both offensive and defensive operations, even to the point of permitting the submarine to lie silently on the ocean bottom.

More than ever before, every ounce of redundant weight must be wrung out of these pressure hulls, and the structural efficiency must be maximized by sophisticated, careful design. Otherwise, with increased depth requirements, the associated greater hull weight might require compensation through reduction in machinery or weapons that would, in turn, be reflected by a penalty on performance. The analysis of submarine hulls thus reaches its most elegant form when searching for techniques of design that produce least weight. It would now appear that the background information and research necessary for this development is of emerging criticality.

The systematic program of naval research that was initiated in 1950 was formulated on the premise that all of the then commonly accepted theories, design procedures and assumptions should be dissected and carefully scrutinized; new mathematical analysis would then be derived wherever necessary and checked by systematic experimentation; finally, conclusions would be formulated into orderly, composite procedures simplified for use by the busy designer and freed from limitations imposed by the semiempirical processes previously employed. Now, ten years later, automatic data processing equipment and computers have made it unnecessary to reduce theory to more tractible but less powerful formulations. New, more sensitive experimental techniques have found application. Many questions raised at the outset of this program have been answe ed, but not all. Many new questions have evolved.

Underlying this inquiry into submarine hulls has been a hard core of basic mechanics concerned with stiffened cylindrical shells under external pressure. While the rudiments of pressure hull behavior were well understood by earlier investigators, the literature is unhappily devoid of any definitive treatment of such pressure vessels, particularly in terms of defining the primary modes of failure and of concepts for least weight design. A "state - of - the-art" summary was invited by the Pressure Vessel Research Committee for presentation by this current author at its annual meeting in 1955, and at that early stage of renewed research it was necessarily speculative and programmatic. Subsequently, in 1958, a special study on feasibility of pressure hulls for deeply submerged submarines was prepared for the National Academy of Sciences.[5] Part I of that report set forth the analytical guides for the structural design of pressure hulls. Freed of security material, it forms the basis of this current paper. Text of the NAS report has also been related to the broader question of submarine design in a recent paper by Arentzen and Mandel.[49]

Description of Pressure Hull

For reasons of brevity, attention is directed exclusively to the main pressure hull, divested of all secondary and tertiary components such as tankage, bulkheads and machinery foundations. It then consists essentially of geometrically pure cylindrical and spherical forms

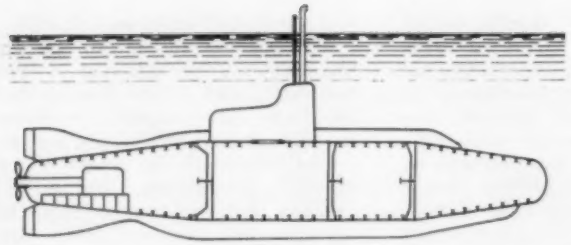


Fig. 1—Simplified schematic diagram of typical pressure hull

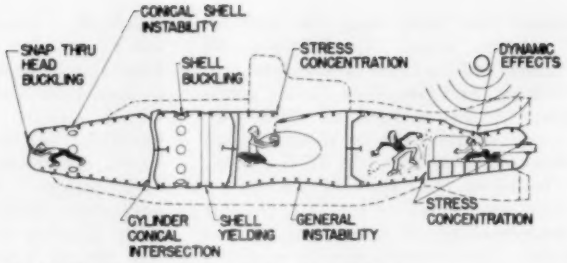


Fig. 2—Significant modes of structural failure

depicted in Fig. 1. For contemporary operating depths, the thickness of shell, h, is on the order of 0.006 the diameter, 2R—proportions, incidentally, very close to the ratio of the thickness of an egg shell to the diameter of the egg (or the thickness of cigarette paper compared to the diameter). For elastic stability, the cylinder is fitted with regularly spaced stiffening rings of H or I cross sections. For hydrodynamic streamlining, the hull is most often conically tapered at the ends. Internally, it is compartmented by bulkheads to restrict flooding, should watertight integrity of the hull be accidentally breached.

The design process usually evolves as follows: Furnished with operating requirements of speed, endurance, range and weapon system, a submerged displacement is estimated. Then, based on certain experience indices, a number of permutations can be established relating length, diameter and hull form (prismatic coefficient).[1,49] Selection can then be made of the diameter to accommodate the necessary internal equipment, to provide convenient arrangements and to minimize hull drag

Operating requirements of depth would also have been specified on the basis of desired tactical performance. More often than not, this depth has been arrived at as a compromise with weight allowances for hull structure, mostly on the basis of what was estimated as possible rather than what was required for military reasons. With an agreed upon safety margin, collapse depth is then established. Thus, with the independent variables of depth, material properties and diameter fixed, computations can be made of shell thickness, the spacing of ring stiffeners and the area and shape of stiffener cross section to develop the requisite collapse strength.

Modes of Failure

When deriving rational theory and planning corroboratory tests, it is advantageous to identify, to isolate and, if necessary, to postulate all independent modes of failure—then to pursue the analysis of each separately. The significant primary modes of hydrostatic collapse of stiffened cylindrical shells are suggested by the cartoon of Fig. 2. With emphasis focused on this cylindrical shell, stress concentrations around openings, dynamic effects of enemy attack and other details are necessarily neglected.

These primary modes of failure are characterized by the physical appearance as well as the inferred collapse mechanism as:

1. Buckling of the shell in between rings, manifested by a plurality of lobes girdling the shell.
2. Yielding of the shell in between rings, characterized by an axisymmetrical accordian-shaped pleat.
3. A general instability mode of failure or "over-all collapse" in which the shell and stiffeners collapse simultaneously from one end of the stiffened cylinder to the other, in a mode shape associated with two to five circumferential lobes.

Shell buckling is further illustrated in Fig. 3, which shows the interior of an externally stiffened cylinder in which a large number of shell lobes have developed. Theoretically, anywhere from 15 to 25 may occur around the periphery of those shells most often associated with submarine hull geometries. Lobes in adjacent bays are staggered. Even after buckling first occurs, the shell may sustain considerable overpressure, until local rupture at a creased lobe ensues. A full development of all lobes rarely occurs prior to complete loss of strength.

Shell yielding is shown in Fig. 4. It is a mode of failure anticipated by theory for many years but observed distinctly for the first time about 1951.[6] In this mode, the shell exhibits an axisymmetric pleat which may extend either partly or fully around the cylinder.

Whether the hull is predisposed to fail between rings by interbay buckling or by yielding depends upon the geometry, the yield strength and the Young's Modulus of the material. For instance with the shell relatively thin, the stiffeners widely spaced, Young's Modulus relatively low and the yield strength relatively high, the buckling mode is more likely to

Fig. 3—Collapse in shell buckling mode

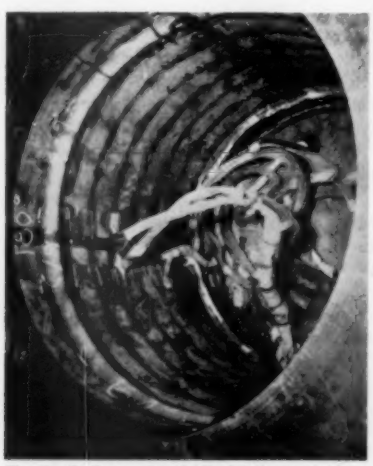


Fig. 4—Collapse in shell yielding mode

occur. Conversely, as in the analogous case of a squat column, if the shell is thick or stiffeners relatively close, Young's Modulus high and yield strength relatively low, the yield mode of failure is more likely to occur. Although the demarcation between these modes is not sharp, the nondimensional parameter, λ, can be used incidentally to discriminate between failure modes.

General instability failure is demonstrated in Fig. 5 and involves a mechanism similar to that for shell buckling except that the collapse simultaneously involves stiffeners and shell. In broad terms, it may occur instead of either of the other two modes if the stiffened cylinder is unusually long or if the stiffeners are too widely spaced or too small.

In test models, failure seldom evolves exclusively in a pure mode—that is, more than one may occur simultaneously or in rapid succession. Moreover, the presence of initial imperfections in shape cloud both the analysis and the interpretation of experiments, even when a pure mode is manifested. There is merit, nonetheless, in pursuing the mathematical analysis of each mode of failure independently and in designing experiments which induce a simple and unambiguous collapse mechanism. As will be enlarged upon subsequently, for optimum design, failure may be desired as a "one-hoss shay" wherein collapse by all three modes occurs simultaneously. Achievement of such optimum design is, however, rare. Limitations of present knowledge on out-of-roundness and strain-hardening seriously block any least-weight design patterned after this idealized concept.

Instability of Cylindrical Shells

The analysis of stiffened cylinders subjected to external pressure was stimulated in the mid-19th century when flues were observed to fail in fire-tube boilers. Analysis was not very elegant. As a matter of fact these tubes, initially free of stiffeners, were designed as though they were subjected to internal pressure (sic) and the wall strength computed entirely on the basis of hoop stress:

$$p = \frac{h\sigma_y}{R} \qquad (1)$$

Unhappily, the tubes collapsed into an elliptical or flat shape at less than design pressure and empirical tests were then conducted to find means of preventing such premature failure.[7] Strength was previously known to be a function of wall thickness. From these tests, load-carrying capacity was found also to be a function of the specific material employed and of tube length, but the exact properties influencing strength were not then identified. This latter discovery immediately prompted introduction of stiffening rings or bulkheads so as to reduce the unsupported length of tube, and thus to improve its pressure resisting qualities.

That these tubes failed by buckling was recognized subsequently through analysis of infinite, unstiffened tubes by Bryan[8] and Bresse.[9] The significant material property was then found to be Young's Modulus. The buckling strength was found to be a power of the thickness rather than of the thickness directly as indicated by the membrane equation (1):

$$p_{cr} = \frac{2E}{1-\nu^2}\left(\frac{h}{2R}\right)^3 \qquad (2)$$

In 1914 von Mises[10,11] had, in his design studies for German submarines in World War I, analyzed a finite cylindrical shell and properly introduced the parameter of unsupported shell length, L. Among other consequences of his theory, it was found that, although the infinite tube buckled into an elliptical mode with two lobes, shorter tubes would be predisposed to a larger number of regular circumferential lobes. The exact number at failure, n, can be readily computed from von Mises' analysis:

$$n = \sqrt[4]{\frac{56.48R^3}{Ih}} \qquad (\text{for } \nu = 0.3) \qquad (3)$$

It has been found that experimental confirmation of predicted

Fig. 5—Collapse in general instability mode

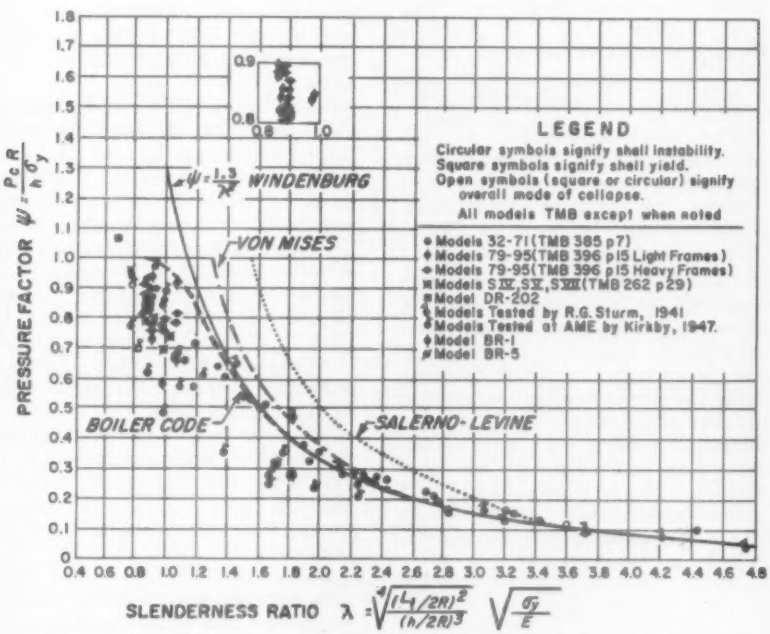

PRESSURE FACTOR $\psi = \frac{P_{cr}R}{h\sigma_y}$
SLENDERNESS RATIO $\lambda = \sqrt[4]{\frac{12L/2R)^2}{(h/2R)^3}}\sqrt{\frac{\sigma_y}{E}}$
$\psi = \frac{1.3}{\lambda^2}$ WINDENBURG
VON MISES
BOILER CODE
SALERNO-LEVINE
LEGEND
Circular symbols signify shell instability.
Square symbols signify shell yield.
Open symbols (square or circular) signify overall mode of collapse.
All models TMB except when noted
Models 32-71 (TMB 385 p7)
Models 79-95 (TMB 396 p15 Light Frames)
Models 79-95 (TMB 396 p15 Heavy Frames)
Models SIX, SX, SXII (TMB 262 p29)
Model DR-202
Models Tested by R.G. Sturm, 1941
Models Tested at AME by Kirkby, 1947.
Model BR-1
Model BR-5

Fig. 6—Curve showing theoretical and experimental results for shell buckling

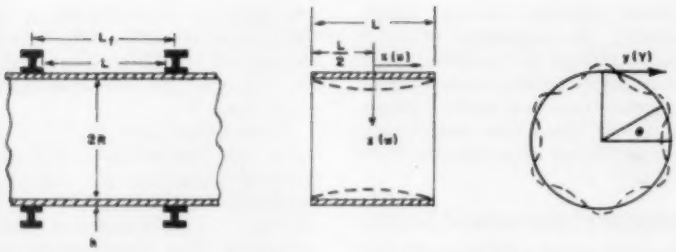


Fig. 7—Shell buckling configuration considered by von Mises

modal shape was not a significant indicator of the accuracy of theory—that is, shells which buckled in the predicted mode shape often did not sustain the predicted pressures.

The analysis of von Mises was immediately applied to submarine design although full confirmation by experiment awaited tests by Windenburg beginning in 1929.[12,13] These experimental observations are plotted in Fig. 6. They are compared with a simplified form of von Mises' analysis, eq. 4, and with a further approximation of the von Mises theory developed by Windenburg, eq. 5. In this latter form, the equation was rendered independent of the mode number, n, by assuming a lobe shape in which length is essentially equal to circumferential distance (an assumption invalid in certain ranges of geometry corresponding to low n):

$$p_{cr} = \left\{\frac{1}{3}\left[n^2 + \left(\frac{\pi R}{L}\right)^2\right]^2 \frac{2E}{1-\nu^2}\left(\frac{h}{2R}\right)^3 + \frac{2E(h/2R)}{[n^2(L/\pi R)^2+1]^2}\right\} \frac{1}{n^2 + {}^1/_2(\pi R/L)^2 - 1} \quad (4)$$

$$p_{cr} = \frac{2.42E}{(1-\nu^2)^{3/4}} \frac{(h/2R)^{5/2}}{[(L/2R) - 0.45(h/2R)^{1/2}]} \quad (5)$$

The nondimensional Ψ - λ coordinates used in this presentation have been frequently found convenient for plotting such data. They are not, however, arbitrary. The "slenderness ratio," $\lambda = \sqrt[4]{3(L/2R)^2/(h/2R)^3}\ \sqrt{\sigma_y/E}$, corresponds to the length/radius of gyration for columns, and the pressure factor, $\Psi = pR/h\sigma_y$, represents the pressure, p, at which buckling failure first occurs in a tube, divided by the pressure at which circumferential yielding occurs in a tube according to the Rankine theory of failure. The selection of the $\Psi - \lambda$ coordinates results directly from the Windenburg approximation which may be written as:

$$\psi = \frac{1.30}{\lambda^2 - \epsilon} \quad (6)$$

where

$$\epsilon = 0.045\,\frac{100\sigma_y}{E}\left(\frac{1-\nu^2}{0.91}\right)^{3/4} \frac{1}{(100h/2R)} \quad (6a)$$

or, when ϵ is small

$$\psi = 1.30/\lambda^2 \quad (6b)$$

It is apparent from Fig. 6 that the experimental data did not completely support theory. However, careful study has revealed that certain of the results cannot validly be compared because failure of test models was not in the purely elastic shell-instability mode portrayed by von Mises. In rough terms, for example, elastic instability may be thought of as occurring in the range of λ greater than 1.2, plastic shell instability in the range 0.9 to 1.2 and shell yielding for λ less than 0.9. In these circumstances where plastic rather than elastic instability occurs, some of the discrepancy between theory and experiment may be attributed to the reduced tangent modulus at the threshold of yielding. Moreover, in some cases, there was a question as to whether the investigator had recorded the initial buckling or the final failure pressure (theory having predicted the former).

Nevertheless, when the results of Fig. 6 were carefully examined, both theory and test data were found in need of further study.[14] The main question of theory related to the nature of boundary conditions at the edges of the finite-length shell. Whereas von Mises' analysis of a single bay involved simple hinged-edge conditions such as shown in Fig. 7, a stiffened cylinder where shell elements are continuous over a stiffener involves a partially or fully fixed boundary condition.

To meet this objection, Salerno and Levine[15] extended the work of von Mises, and their results are represented also in Fig. 6. Agreement with observation is even poorer.

Subsequent review of the data then revealed that, although the experiments had been carefully conducted, in many instances the models departed from perfect circularity and single bay models had indefinite boundary conditions. Attention had been previously focused by Sturm and H. M. Westergaard[16] on the significance of this circularity effect, more recently evaluated by Holt,[54] but even more rigorous analyses discussed subsequently do not explain experimental results.

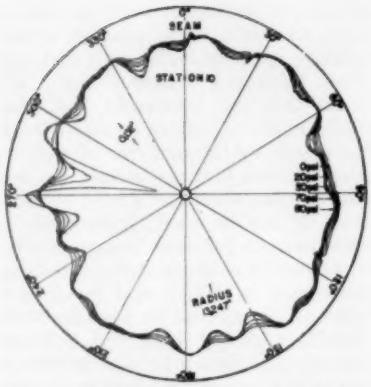


Fig. 8—Circularity measurements during pressure tests of stiffened cylindrical shell

The associated out-of-roundness behavior is perhaps most poignantly demonstrated through precise observations shown in Fig. 8. Circularity was measured before and during application of external pressure. By means of electronic amplification, the radial displacements in the model are greatly exaggerated on the polar plot.[17] In this model, incidentally, initial circularity met specifications corresponding to those for submarine hulls in which out-of-roundness is limited to one-half shell thickness. (With the advent of thicker hulls, this has now been limited to $^1/_2$-in., which is an even more stringent limit but is more easily attainable in thicker plate.)

During application of external pressure, it was observed that initially inward indentations grew larger, whereas initially outward bulges did not generally expand. The phenomenon of buckling could be readily identified both by the sudden noise and visible appearance of a lobe that probably developed when one of the inward enlarging bulges suddenly exploded in amplitude. This condition is indicated on the chart.

There were thus strong indications that the theory by von Mises for a perfect structure could not be readily checked by experiments which involve models of imperfect circularity, albeit small. The question remained, of course, as to just

how much the shell is weakened by its departure from circularity.

Some light was thrown on this issue by tests of two geometrically identical models.[18] One was fabricated by rolling a sheet into a cylindrical form with rings then attached by welding in accordance with usual submarine practice. The other model, however, was fabricated by rolling a thick plate into a cylindrical form, followed by stress relieving; material was then machined from the thick cylinder so as to leave rings integral with the shell itself. The two models, although of the same geometry, thus differed in two important respects: the conventionally fabricated one was less circular and contained residual welding stress not present in the machined cylinder—Fig. 9.

Fig. 9—Buckling failures in geometrically identical models, one machined and one welded following submarine practice

In tests under external pressure the rolled and welded model failed at 390 psi whereas the machined one failed at 540 psi. With only a single test point, it would indeed be improper to conclude that imperfect shells involve this great a loss in strength, but the weakening effect is manifestly clear. The numerical results, however, did not confirm theoretical predictions of Sturm, nor of more exact analyses of noncircularity by Galletly and Bart as well as Bodner-Berks.[19,20] Further discussion of this problem is offered, subsequently,[40] but the essential process of validating theories for elastic instability of perfectly circular shells in the geometric range of practical interest as well as for imperfectly circular shells remain incomplete. Primarily lacking is the theoretical bridge between elastic behavior computed as induced by noncircularity, and the plastically triggered collapse.

Yielding of Cylindrical Shells

A second significant mode of shell failure is by yielding as illustrated in Fig. 4. The notion of yielding in a structure dates back to the earliest rudimentary considerations of the mechanics of materials. For instance, an infinite tube under internal pressure might be regarded as yielding according to the elementary, maximum principal stress (or Rankine) theory of failure when the hoop stress reaches the uniaxial yield stress of the material itself, i.e., $\Psi = 1.0$. Under external pressure, the same yield condition applies. Obviously then, the determination of yielding requires a prior determination of the limiting elastic stress, in terms of the intrinsic property of the material.

In an infinite shell with a perfectly circular cross section, the circumferential and longitudinal membrane stresses are the same with external as with internal pressure. They are axi-symmetric and homogeneous throughout the length. With the introduction of stiffening rings for the purpose of increasing the buckling strength of the tube by dividing it into shorter unsupported lengths, the condition of uniform stress is disturbed. At a stiffener, for example, the radial displacements of the shell are almost certain to be less than at mid-bay. In other words, the shell under external pressure is squeezed inwardly but, at the stiffeners, an interaction occurs by which the stiffening ring is loaded inward radially but in turn reacts to exert outward radial forces on the shell.

In their design analysis for German World War I submarines, von Sanden and Günther evaluated this effect and found the local stress distribution heavily influenced by stiffener area and spacing.[21,22] Their analysis, incidentally, was developed from the well-known fourth-order differential equation which defines the behavior of a beam laterally loaded and resting on an elastic foundation:

$$EI_z \frac{d^4y}{dx^4} = -ky \qquad (7)$$

where k is the modulus of elastic foundation; in this analog $k = Eh/R^2$, $EI_z = Eh^3/12(1 - \nu^2)$. In the case of a stiffened cylinder, the shell contained between two stiffeners is divided into longitudinal strips. One may be isolated for study with lateral forces representing pressure applied on one face of the strip and continuous elastic support provided by contiguous shell elements to react on the other side. In addition, the ends of the strip rested on concentrated elastic supports which represent the radial resilience of the rings. This system of loads and reactions produces a bending effect not present in an infinite unstiffened tube. The longitudinal bending moments, and circumferential moments due to the Poisson effect produce stresses $\sigma_x{}^b$, $\sigma_\psi{}^b = F(x)$ to be superposed on the membrane stresses. Details of this type of analysis are given by Timoshenko.[23]

With this structural configuration, the strains follow the typical pattern of Fig. 10. Circumferential strains vary somewhat between stiffeners, becoming generally higher at mid-bay then at the rings. Longitudinal strains, however, vary sharply along the generator due, of course, to the restraint afforded by the rings. In the illustration, the curved lines representing theoretical strain variations may be compared with the otherwise straight lines that would exist in the absence of such stiffeners.

Also plotted in Fig. 10 are the results of several experiments in which the observations show good agreement with theory.

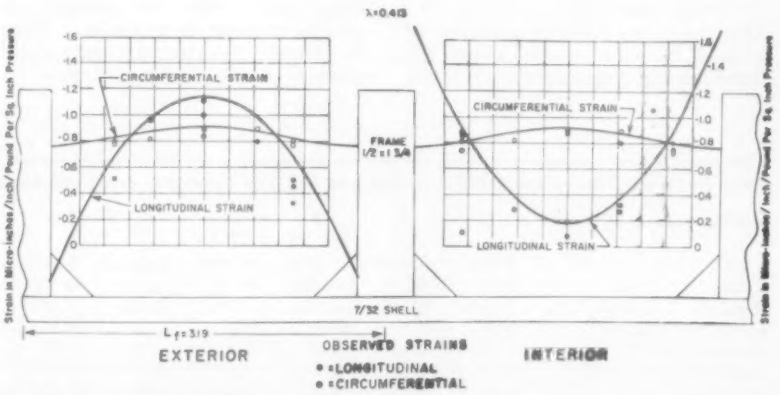


Fig. 10—Comparison of experimental and theoretical strains in stiffened cylinders (TMB Model BR-2)

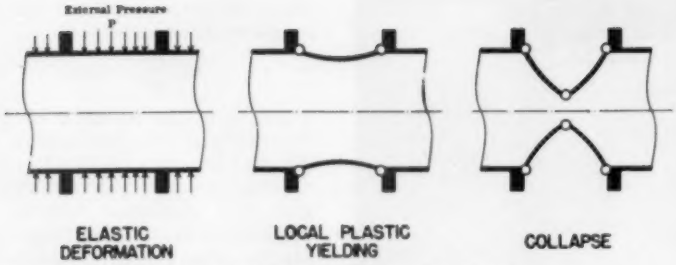


Fig. 11—Hypotheses of yield failure of stiffened cylinders subjected to external pressure

A further refinement in analysis was introduced by Salerno and Pulos[24] to include the nonlinear "beam-column" effect which is present as a consequence of the axial component of pressure acting on a stiffened cylinder. In the beam-on-elastic-foundation analogy, this effect is simulated by the addition of an axial force to the strip under analysis. For the cases thus far studied, this refinement has not been found essential, except in the case of bays adjacent to very rigid rings.[25] Solution of the Salerno-Pulos equations, ordinarily tedious, has been greatly simplified, for stresses at mid-bay by graphical solutions of Krenzke and Short.[26]

Having computed the elastic behavior of the cylinder, it is next necessary to relate the magnitude of elastic stress to some failure condition. It was assumed by von Sanden and Günther that failure in the shell occurs whenever the circumferential stress on the outside of the shell at mid-bay or the longitudinal stress on the inside of the shell at the ring reaches the nominal yield strength of the material. In 1953, realizing that the yield condition was probably more sophisticated, Wenk, *et al.*, suggested that at the very least the von Mises-Hencky yield condition be applied, postulating that failure occurs according to the mechanism shown in Fig. 11.[6] This criterion of failure is expressed in eq. 8, where σ_1, σ_2 and σ_3 are the three principal stresses and σ_y is the stress at which yielding occurs with uni-axial loading, as in a standard compressive coupon test:

$$2\sigma_y^2 = (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \quad (8)$$

In the case of an unstiffened tube under pressure, $\sigma_1 = 2\sigma_2$ and $\sigma_3 = 0$. Then the maximum principal stress σ_1 equals 1.16 σ_y for yielding to occur, rather than $\sigma_1 = \sigma_y$ as in the elementary Rankine theory.

In Wenk's hypothesis, yielding would occur first at the stiffener and then at a somewhat higher pressure at mid-bay. When such yielding spreads sufficiently, both through the thickness and along the shell, collapse by a plastic, axisymmetric instability occurs. Such a mechanism corresponds with the actual observations of pure yield failures. In the absence of a rational theory, it was suggested that (in combination with elastic stresses computed by von Sanden-Günther or Salerno-Pulos) the von Mises-Hencky yield condition be taken at mid-thickness, mid-bay as a necessary, if not sufficient, empirical yield condition to produce failure.[6] Elastic-plastic analysis by Lunchick[27] and Hodge[28] now give a more explicit basis for computing such yield strength. In all theories, incidentally, there is recognition of a certain reserve of plastic instability strength (axisymmetric) over the pressure at which yielding is initiated. None of these theories accommodates strain hardening characteristics.

Although not further elaborated upon in this paper, the elastic deformations given by von Sanden and Günther were tentatively confirmed by Trilling's experiments in 1935.[22] With the advent of electrical strain gages, elastic theories have now been far better confirmed by extensive strain measurements prior to collapse.[6, 29, 30] In many cases, the tests were extended until strength was exhausted. Where the failure was exclusively in the yield mode, it has been possible to compare the observed collapse pressures with those predicted by various theories to determine that which best describes the phenomenon.

Results are listed in Table 1 for a series of eleven models. Along with the description of the geometry and material of the models, there are given ratios of the predictions of strength by theories of Lunchick, Hodge and the hypothesis by Wenk with respect to the maximum observed pressure. All of the predictions are in substantially close agreement with observations, considering the variation in yield properties at different locations in the shell and both the small departures from straightness of the generator and residual stresses due to welding. It would be difficult to conclude that one theory is more valid than another. Thus, on the basis of the results so far available, the semi-empirical hypothesis has an advantage of simplicity of calculation. Recent tests by R. C. Dettart at Southwest Research Institute show that all of these theories are conservative when dealing with materials that lack a well-defined yield point.

Of practical importance as a subsidiary result was observation by Wenk that with closely spaced stiffeners, i.e., $\lambda < 0.7$, pressure factor, Ψ, could be developed far in excess of 1.0.[6] Now a value of $\psi = 1.16$ is a straight forward consequence of yielding in an unstiffened tube, using Hencky-von Mises criteria. But with closely spaced stiff-

Table 1—Comparison of Predicted and Observed Collapse Pressures in a Yield Mode

Model no. →	1	2	3 BR-7M	4 BR-7	5	6	7	M-1	M-2	M-3	M-4
$h/2R$	0.0088	0.0078	0.0078	0.0060	0.0081	0.0047	0.0058	0.0065	0.0065	0.0066	0.0064
$L_f/2R$	0.114	0.095	0.095	0.110	0.202	0.109	0.168	0.141	0.141	0.141	0.141
$A_f/L_f h$	0.646	0.745	0.745	0.282	0.288	0.479	0.228	0.500	0.500	0.490	0.510
σ_y, in kips/sq in.	46.8	47.5	59.2	44.8	47.1	49.6	47.0	82.5	78.4	82.5	55.9
Hodge analysis[a]	0.91	0.91	0.98	1.03	0.97	1.03	1.06	1.11	1.08	0.92	0.84
Lunchick analysis[a]	0.98	0.93	1.01	1.00	0.97	1.03	1.03	1.12	1.09	0.93	0.85
Wenk hypothesis[a]	1.01	0.95	1.03	1.03	0.99	1.07	1.09	1.20	1.16	0.99	0.89

[a] Ratios given of predicted/observed pressures.

eners, some of the load in the shell is transferred and absorbed by the rings, thus moderating mid-bay shell stresses and admitting of higher load-carrying capacity. Implications of this minimum weight relationship, colloquially termed "low λ design," are discussed subsequently.

Another step toward refinement in design is accommodation of the tendency for stresses in the shell near oversize rings (or bulkheads) to exceed those in a typical bay so as to diminish yield collapse strength locally. While this weakening effect may seem small (only 5 to 10%), it has been found worth while to compensate for it by increase in stiffener size and in spacing at these "end bay" locations, thus increasing strength with virtually no increase in weight. An analysis by Short and Bart[25] permits computation of this effect, by applying the principles of Salerno-Pulos. Tests by Keefe and Overby[31] confirm theoretical predictions. Of course, with increased end bay spacing, a recheck is necessary of interbay buckling strength.

General Instability of Stiffened Cylinders

The appearance of the general instability or "over-all collapse" mode of failure was shown in Fig. 5.

Although the mechanisms of shell and general instability are similar, the latter mode of collapse has defied rigorous analysis until recent years. Early work by Tokugawa[32] has been questioned despite its long use in submarine design, and the theories more recently constructed by Kendrick[33,34] are now regarded as far more satisfactory.

In buckling problems of this type, solution has been necessary by energy (Rayleigh - Ritz) methods. As a consequence, buckling pressures have been computed entirely on the basis of the *assumed* buckling configuration. Out of all assumed buckling shapes, the one considered most significant is that giving the lowest buckling pressure while adequately meeting the boundary requirements. Unfortunately, it is never certain that some other undiscovered buckling shape would not give even lower values. Kendrick has developed three analyses for different assumed boundary conditions; Kaminsky has investigated yet another.[35] While observations have been sought of the actual buckling pattern, the process is thus far so transitory as to defy examination. Most physical evidence of buckling resides in the damaged shell *after* deformations progressed far beyond the onset of yielding. In the meanwhile, an important simplification was derived by A. R. Bryant and placed in graphical form by Reynolds.[36] Although easier to apply, Bryant's approximate equations below produce some errors in certain ranges of geometry:

$$p_{cr} = p_s\left(\frac{L_b}{R}, \frac{h}{R}, n\right) + p_f\left(\frac{I_e}{L_f R^3}, n\right) \tag{9a}$$

where p_s is buckling strength of shell between bulkheads and p_f is buckling strength of frame, per unit length of shell

$$I_e = \frac{A_f a^2}{1 + (A_f/L_e h)} + I_f + \frac{L_e h^3}{12} \tag{9b}$$

where $L_e = 1.57\sqrt{Rh}$ if $L_f > 2\sqrt{Rh}$, and a is distance from median surface of shell to ring centroid.

Stiffener area, A_f, and moment of inertia, I_f, as well as spacing influence general instability strength. Also, the length of stiffened cylinder, L_e—that is, the distance between holding bulkheads in a submarine—is as important a parameter for general instability as is stiffener spacing for shell instability. In actual design, however, the boundaries of a finite stiffened cylinder may be defined by intermediate heavy rings instead of bulkheads. While the exact size of ring necessary to qualify as such a boundary has never been rigorously described, it would appear that the ring should be proportioned to develop a radial rigidity equal to that of the bulkhead plating. Kendrick, incidentally, has derived an analysis in which he considers large ring stiffeners systematically intermingled with somewhat smaller ones, and a variety of such combinations may be conceived as potential means of maximizing the strength-to-weight ratio.

Experimental confirmation of the general instability theory has been undertaken during the last 6 yr, perhaps more thoroughly than that of any other feature of submarine structure. Since it was recognized that these theories applied to a perfectly circular structure, initial tests were conducted using machined rather than built-up models. (As shown later, the quantity, P_{cr}, which represents the buckling strength of a perfect shell is required in the rational strength analysis of even imperfectly circular shells.) From a rather elaborate program where model length, ring size and ring spacing were independently varied, validity has been generally but not unequivocally developed of Kendrick's work.[37-39] A summary of results is given in Table 2 with test pressures in nondimensional terms as the ratio of predicted pressure to that observed. Of course, the closer are these ratios to unity, the better is the agreement of test with theory. For the examples cited, the greatest error in Kendrick's theory was on the order of 20%. Most agreement was better.

There has remained a rather vigorous difference of opinion as to whether or not the results cited do or do not fully confirm theory.[40] Most

Table 2—Ratios of Predicted to Observed Collapse Pressures in a General Instability Mode

(a) With Ring Size Variable

Model no.	Ratio of ring sizes	Kendrick I	Kendrick III (hinged ends)	Kaminsky (clamped ends)
1 (4)[a]	1	1.012[c] (4)[b]	0.976	1.637
2 (4)	1	0.989 (4)	0.937	1.607
3 (3)	2	0.994 (3)	0.920	1.714
4 (3)	3	0.960 (3)	0.842	1.534
5 (3)	4	1.200 (3)	0.997	1.589
6 (3)	4	1.160 (3)	0.967	1.542

(b) With Stiffened Cylinder Length Variable

Model no.	$L_b/2R$	Kendrick III (hinged ends)	Kaminsky (clamped ends)
1 (3)	2.61	0.84 (3)	1.42 (3)
2 (3)	3.36	0.78 (2)	1.40 (3)
2A (3)	3.36	0.79 (2)	1.41 (3)
3 (2)	4.31	0.67 (2)	1.70 (3)
3A (2)	4.31	0.69 (2)	1.72 (3)
4 (2)	5.16	0.76 (2)	2.05 (2)
4A (2)	5.16	0.78 (2)	2.10 (2)
5 (2)	6.85	0.92 (2)	2.06 (2)

[a] Observed number of lobes.
[b] Computed number of lobes.
[c] Ratios given of predicted/observed collapse pressures.

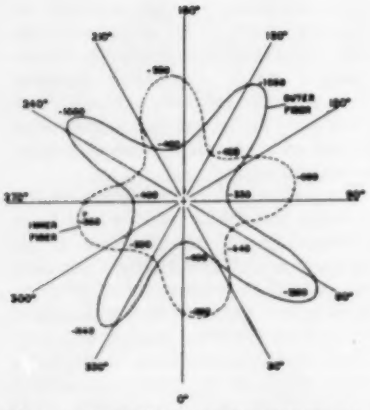
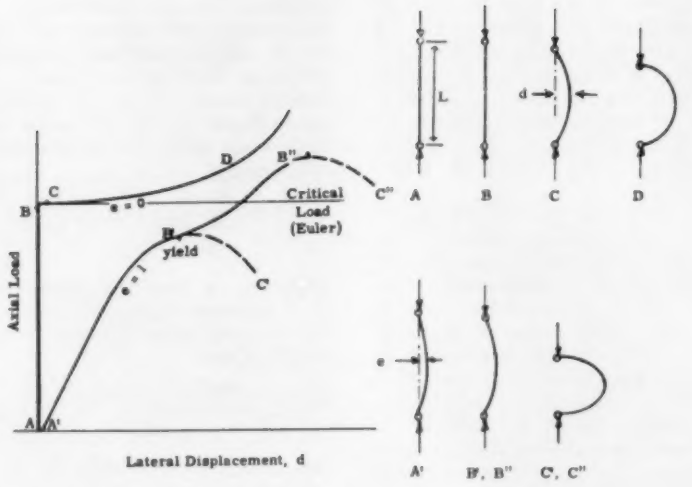


Fig. 12—Nonuniform elastic strains observed in machined model at threshold of general instability failure



C is buckling load of perfect column; B' is maximum load of eccentric column

where $\sigma = \sigma_y < \sigma_{cr} = \frac{\pi^2 E I}{A L^2}$

Fig. 13—Displacements of perfect and imperfect columns

baffling has been the fact that the models had more or less rigid end support, yet experimental data agreed far better with theory for hinged ends (Kendrick) than with theory for fixed ends (Kaminsky). In interpreting this situation, Galletly, *et al.*, in a recent paper wrote as follows: "There now develops a serious question as to whether the form of the buckling configuration assumed by Kaminsky and by Nash for fixed ends is correct. It is conceivable, at least, that some other postbuckling pattern actually exists involving less energy of deformation but which has a sharp curvature at the ends compatible with the condition of no rotation of the generator, and which in the middle corresponds in shape to that for simple support. If this pattern is the real one (i.e., the one which describes the actual physical phenomenon), the P_{cr} calculated by Kaminsky would be too high, so that the actual differences between clamped and simple support might not be so great after all. This possibility can only be illuminated from future theoretical analyses in which other buckling configurations satisfying clamped end boundary conditions are tried."

These conclusions have recently been substantiated by Reynolds and Blumenberg,[38] Kendrick's published criticism of the Galletly paper notwithstanding.

Further Discussion of Imperfect Circularity

Since, in the case of shell instability, the formation of a visible lobe which precipitates failure was observed as a progressive and accelerated growth of an initial indentation, it was thought instructive to make careful measurements during tests of the machined general instability models to investigate this mechanism of failure in more detail. Strain gages were thus installed on both the inside and outside of ring stiffeners. Sample observations are shown in Fig. 12. In this instance, the strains were measured up to 650 psi, the very threshold of a failure which subsequently occurred at 655 psi.[40] Most significant was manifestation of the four-lobe pattern of strains, indicating that the machined shell was not compressing with axial symmetry as might have been expected. Rather, the lobes which became visible at failure were apparently present in prior embryo form even at lower pressures.

From these observations, it was apparent that initial departures from circularity of the stiffeners could adversely affect strength and, S. Kendrick and Wenk[41] arrived at the same conclusion simultaneously, although independently, that rigid adherence to circularity is more vital for the stiffeners than for the shell itself.

General instability failure, instead of being a case of elastic instability, was thus explained as a case of local ring yielding induced by bending at the points of maximum departure from circularity; failure is thus precipitated in what only *appears* to be a general instability mode. This, in fact, was Sturm's thesis for shell instability failure.

For purposes of further explanation, because this phenomenon is of such importance to submarine design, reference is made to an analogy with perfect and imperfect columns. In Fig. 13 are plotted lateral displacements of an axially loaded bar for two initial states of complete straightness and of slight curvature. For the initially straight bar, no lateral displacements occur until the Euler buckling load is achieved. At that time, theoretical bifurcation occurs in displacements. When the buckling load is exceeded, the bar may theoretically either remain straight or it may bend and develop large lateral displacements. In fact, this it usually prefers to do. Such lateral displacements, however, occur with *increasing* load so that, assuming perfect elasticity, conditions of equilibrium exist in the postbuckling state at loads *greater* than the buckling load.

With small initial imperfections, however, lateral displacements in the column develop as shown in Fig. 13 throughout the entire loading range and grow with increasing load; the load carrying capacity is itself arrested by yielding.

In Fig. 14 and eq. 10, this behavior is examined qualitatively. It may be seen that the imperfect bar develops both direct and bending stress. The bending stress, however, increases nonlinearily with the load because the initial eccentricity which imposes a moment on the bar enlarges itself as the load increases:

$$\sigma = \frac{P}{A} + \frac{P_e}{S}\frac{1}{1 - P/P_\sigma} \quad (10)$$

where P is the axial load on the column; S is section modulus of the column cross section.

The same phenomenon occurs in

Fig. 14—Stresses in imperfect columns and rings

the case of an imperfectly circular ring subjected to external pressure. The corresponding equation is also given:

$$\sigma = \frac{pR}{h} + \frac{6pR}{h^2} \sum_{n=2}^{n=\infty} u_n \cos n\theta \left(\frac{1}{1 - p/p_{crn}}\right) \quad (11)$$

It should be noted that the total stress comprises a membrane term and a bending term, which is a periodic function of central angle. The nonlinear effect is identified with the factor $1/(1\text{-}p/p_{cr})$. Here, the small initial imperfection, u_o, grows as the load p increases. In fact, as p approaches the buckling load, p_{cr}, the denominator of the nonlinear factor approaches zero and the term, itself, bursts to infinity. The manner in which small initial imperfections explode as the load approaches the buckling value is thus readily explained.

One other detail bears elaboration. In eq. 11 and Fig. 14, the departures from circularity were assumed configured identically with the buckling mode. It is entirely possible and highly probable that forms of out-of-roundness are far more complex. In that case, it would be necessary to describe the departure from circularity in a Fourier series, each term of which corresponds to a periodically varying imperfection of amplitude u_n. When these are superposed, the actual shape would be analytically described. The weakening effect would then be expressed as a sum of terms, each containing a u_n and the p_{crn} of that mode. For a ring, this would be given by eq. 11 and buckling loads by the equation below:

$$p_{crn} = \frac{(n^2 - 1)EI_z}{R^3} \quad (12)$$

It is this complication that makes analysis of shell out-of-roundness unmanageable, for departures from circularity vary not only around the shell but also along the shell, possibly in a random mode. A statistical treatment of this quality has been proposed by Donnell[44] as is discussed subsequently as large-deflection buckling.

Imperfect circularity of rings and its weakening effect on over-all collapse are far more amenable to theoretical treatment, both because defects may be described in two rather than three dimensions and, because in any harmonic analysis of imperfections, modal shapes through $n = 6$ should suffice for general instability; with shell instability, up to 25 terms might be required. It is true, however, that a few terms usually dominate the series. An approximate treatment of the problem, while subject to certain theoretical shortcomings, provides a physical reasoning that permits interpretation for engineering design, as follows: The ring stiffeners are loaded radially by the shell as sketched in Fig. 14 with forces described by equations of von Sanden and Günther. These loads develop by reason of interaction with the shell according to the mechanism described earlier, and are assumed to be axisymmetric (a simplification known to be approximately). Each ring is then isolated for analysis and, for reasons of analogy, considered to be elastically supported by the shell. Buckling strength of such a ring system is taken equal to the general instability strength given by Kendrick of the perfectly circular stiffened cylinder to which the ring system corresponds. The bending stress in such a ring was previously described.

Failure is conservatively assumed to be precipitated at the instant of local yielding of the ring-flange. It will be noted here that degradation of strength due to out-of-roundness can be compensated either by changing the size of the stiffener so as to increase its flexural rigidity or by increasing the size and reducing the spacing of the stiffener so as to improve the general instability value and thus moderate the amplification effect.

Numerous experimental observations have been made which confirm this mechanism. The nonuniform strains around a ring are also demonstrated in Fig. 12. In addition, the nonlinear variation of strains with pressure has been observed in numerous models with sample data given in Fig. 15. It should be

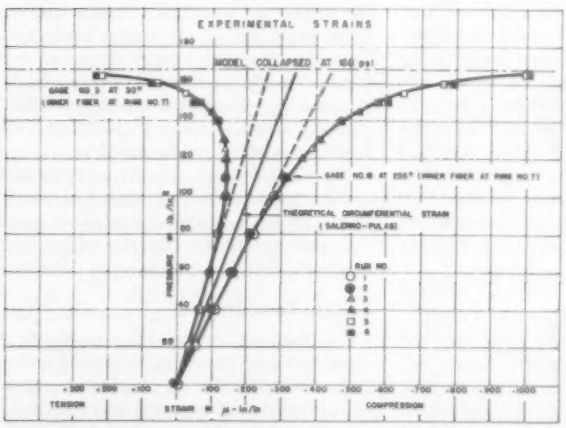


Fig. 15—Nonlinear elastic strains in imperfect stiffened cylindrical shells

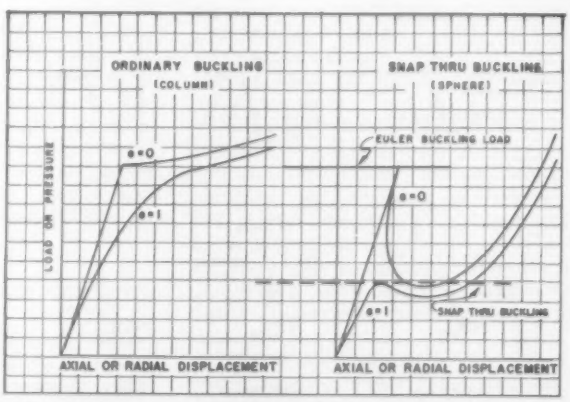


Fig. 16—Schematic representation of Snap-through buckling (e represents initial eccentricity)

strongly emphasized, that this nonlinear behavior is fully reversible and repeatable; it is a consequence not of yielding but rather of the nonlinear elastic effect mentioned earlier.

Imperfect Circularity and Large Deflection Buckling

Unfortunately, the elastic instability of cylindrical shells is even further obscured by another possible mechanism usually referred to as "snap-through buckling," a phenomenon more familiar in buckling failures of spherical shells. Their behavior has been explored by what is regarded as "large displacement" theory which permits definition of the behavior of the structure in the postbuckling condition after displacements have grown so large as to violate the basic assumptions of the more usual small deflection theory.[42]

The phenomenon is best described as follows: Consider, first, classical but large displacement buckling of a perfectly straight column. Under axial load, such bars for zero initial eccentricity demonstrate equilibrium in a postbuckling configuration at loads greater than buckling value as shown in Fig. 13. Now it has been discovered in some types of structures that an entirely different, "snap-through," postbuckling phenomenon occurs. It is the mode experienced with the snapping of the bottom of an oil can, a toy cricket or the dimpling of a ping-pong ball; it is best described graphically, as shown in Fig. 16.

Especially to be recognized here is that postbuckling configurations of equilibrium can exist at loads *less* than rather than *greater* than the Euler buckling value. Moreover, the implicit possibility exists of sudden failure at such lower loads through some externally stimulated mechanism without the load necessarily rising to the first peak of the curve. Only by this process can failures be explained of spherical shells under external pressure at considerably less than the classical value, and also for cylindrical shells under axial loading.

It has been variously postulated that such snapping can be triggered by potential energy associated with bending at initial imperfections or by kinetic energy of impact or vibration. In the case of the imperfect shell, the phenomenon is described for the ordinary buckling by the curves identified by $e = 1$. For snap-through, disagreement among authorities still exists as to whether the peak or valley in that curve represents, for practical purposes, the valid maxima of load.[43, 44]

Recent theoretical[44] and experimental[45] studies have confirmed the fact that such snap-through can occur in cylindrical shells under external pressure, although the postbuckling equilibrium loads are usually not much less than those given by the small deflection theory.

Inside vs. Outside Ring Stiffeners

American designers have traditionally located ring stiffeners on the outside of the shell of nonnuclear submarines, and the British on the inside. Selection has usually been based on convenience or preferences for internal arrangements and hull form rather than on the proved superiority of strength of one structural system over the other. In those few cases where comparisons have been possible, test results indicate that cylinders using outside rings are stronger, other factors being equal.

Two unrelated theories have been offered in explanation. In the first,[46] the minute initial tilt of T-stiffeners, as a consequence of inevitable fabrication irregularities, has been shown to be the cause. From Fig. 17, it can be seen that radial forces transmitted by the pressure-loaded shell to the toe of the stem tend to align the T so as to reduce tilt when it is situated on the outside; conversely if the T-stiffener is on the inside, the same type of load tends to increase the tilt. In this latter case, continued torsional rotation eventually overstresses and plastically cripples the flange. With inside rings, tilt even on the order of three degrees was found detrimental, with failure triggered by local yielding of the ring-flange as evidenced by tripping of the ring and followed by a general instability mode of collapse.[46]

A similar effect has been reported from welding distortion.[47, 48] Here, welding of a T-stiffener on the outside would appear to cause the shell generator to bow outward initially, whereas welding of rings on the inside produces an opposite effect. These initial distortions alter the elastic stress distribution produced in the shell by external pressure—in the case of the outward bowed shell, favorably. Limited tests by Krenzke[29] comparing internally and externally stiffened models show a yield collapse strength 5–7% higher with the outside rings. Tests also hint at a mild weakening effect of residual welding stresses in the yield mode if stiffeners are inside[48] but not if outside—a phenomenon needing further investigation before conclusions can be safely drawn.

Even though residual rolling and welding stresses do not seem to have a marked effect on the static collapse strength, comparative tests show that the onset of nonlinear inelastic behavior is considerably deferred in those models freed of residual stresses by deliberate relief. This condition may reveal itself to be significant with cyclic loading.

The increased use of inside rings on the more recent nuclear powered boats of single hull construction has focused attention on the need to evaluate this phenomenon.

Cyclic Loading

In the past, design philosophy for submarine pressure hulls has closely followed that for commercial pressure vessels in treating the load as static and considering proof of satisfactory strength to be demon-

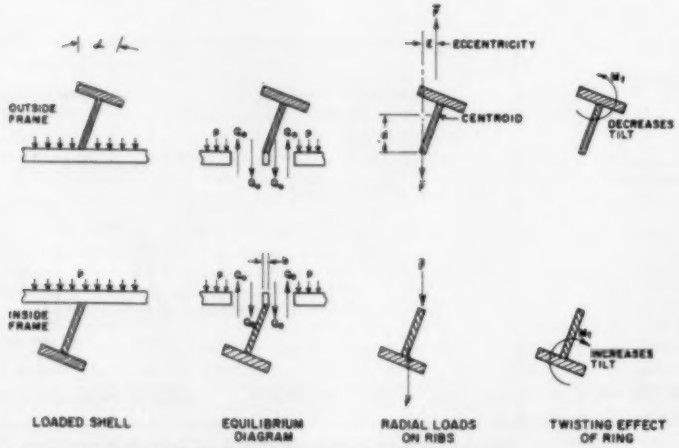


Fig. 17—Effects of tilted stiffener on strength of shell

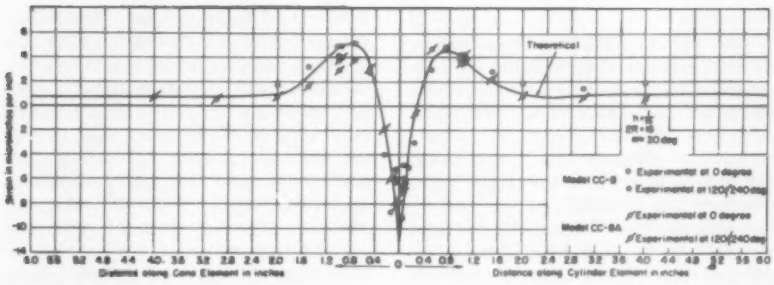


Fig. 18—Comparison of theoretical and experimental strains at intersection of cone and cylinder

strated by a hydrostatic overpressure test. In recent years, however, attention has been focused on the cyclic nature of service loads in pressure vessels (particularly those employed in nuclear reactors) and on the need to design accordingly. Substantial programs by the Pressure Vessel Research Committee at École Polytechnique and at Southwest Research Institute were focused on this problem.

The same phenomenon has been predicted as occurring in submarine service.[5, 49] The cyclic nature of the loading arises here from normal service, simply by frequent diving from surface to operating or to intermediate depths. Especially with high speed submarine operation and long underwater endurance, a large number of such cycles may be accumulated in the lifetime of such a boat.

The reader probably wonders how such a fatigue problem is of significance in submarine design where, in the first instance, the hull is apparently everywhere in compression, and where, even with the most conservative estimates, the service would never exceed 50,000 cycles.

While it is true that virtually all of the hull material designed according to principles discussed previously would be stressed in compression, even though varying longitudinally over quite a range, hard spots nevertheless exist at bulkheads and more particularly at the intersection of cones and cylinders. Intense stress concentrations occur, because the tensile component of local bending is not compensated by the compressive membrane strain. Under external pressure, a net tension then develops.[50, 51] An extreme case is demonstrated in Fig. 18. Fatigue is equally significant in those cases where pressure induced stresses are everywhere compressive, but at such hard spots so intense that the yield point is greatly exceeded locally on initial loading. Relief of pressure is then attended by a stress reversal so that intense residual tension remains when all loading is removed. Such tension then disappears but reappears each time pressure is subsequently alternated—with the conventional fatigue phenomenon then manifested.

It is also recognized that, if the local concentration effect is very great, fatigue failure can occur in a relatively small number of cycles (at far less than 50,000), certainly if the strains are sufficiently high. This phenomenon of low-cycle high-stress (plastic) fatigue is now being widely studied. In the past, it has often been assumed that the ductility of the material could accommodate local stress concentrations so that the yielding at first application of load would erase any effect of stress concentration and leave the structure, after shakedown, in a fully elastic condition with no loss in static strength. A similar condition was thought to occur when severe compressive stress was relieved on the initial application of load, even though followed by residual tension.

It is beyond the scope of this present paper to discuss the process of cumulative fatigue damage in its application here. However, such considerations must be given diligent attention in those cases where the desired high performance of structure has caused the designer to minimize weight. Although designing for static strength, the designer must then examine the consequences in terms of occurrence of tension in the structure and of the possibility of local fatigue failure.

Factor of Safety

As in all engineering structures, the factor of safety is introduced in design to accommodate unknowns or limitations in theory, variables in materials, imperfect workmanship or inspection, degradation from corrosion, and unknowns in service loading or such hazards as accidental overload.

On the latter point, the hydrostatic service loading of a submarine is far more precisely defined and subject to control than seaway loading on surface ships. Nevertheless, hazards in contemporary submarines obviously occur if control is lost during a dive since, in that situation, the depth margin between operating and collapse limits could be exhausted in less than a minute by a high-speed submarine overshooting the service limit. On the other hand, low-speed ships such as might be employed for oceanographic research are confronted with somewhat less risk of skidding beneath the specified operating depth.

On this point alone, a moot question arises as to whether the submarine safety factor should continue to be expressed as a ratio between collapse and operating depth or whether it should be specified in terms of various depth increments which depend upon specific performance characteristics of different ships.

It must be recognized that the confidence with which these current 1.5–2.0 safety factors are employed is fortified by a number of design, fabricating and test operations that may be economically unacceptable in the case of commercial structures. In the first instance, each submarine is custom designed and every component therein is examined in detail by application of sophisticated theories. Handbook approaches have been rejected. Such design is conducted with just as much precision as the science allows. In recent years, however, the highly skilled man power required for such effort has been markedly conserved with the advent of automatic computers and data processing. Projected designs are always confirmed by small scale tests wherein the predicted collapse pressure is confronted with model performance data. The validity of this process is elaborated upon subsequently.

Finally, present submarine practice involves widespread X-ray inspection of welds, the enforced chipping and repairing of defects, the careful sampling of plates used in construction, and far more than the usual care in assembly to ensure conformity with specifications for out-of-roundness. Such fabrication processes are costly.

With deeper operation, the correspondingly thicker hulls can be fabricated more circularly (if out-of-roundness is defined as a percent

of shell thickness) and, in turn, are less sensitive to weakening effects of imperfect shape. Thus, hazards which accompany loss in control, unknowns in design and workmanship might diminish relatively in the deep submergence submarine so as to permit adoption of even lower safety factors then are currently employed. Moreover, if a design were based, for example, on an operating depth of 12,000 ft, with a safety factor of say 1.33, the floor of the ocean itself will, in most instances, provide a limit on accidental overload.

Model and Full Scale Tests

Notwithstanding the extreme care with which research on stiffened cylinders has been undertaken and the power of experimentally confirmed theory, there remains a strong desire to verify the strength of each new submarine design. Historically, this has been accomplished through tests of small scale models. Such models are fabricated as geometrically similar to the initial prototype design as is possible, usually with simulation of an entire submarine section between one pair of holding bulkheads. From dimensional analysis, it can be shown that the hydrostatic pressure at which failure occurs in a full-scale structure is exactly equal to the pressure at which failure occurs in a geometrically similar model. With submarine hulls, this theorem implies that imperfections in shape must be appropriately scaled and that the yield strength and shape of stress-strain curve of material in the model must be identical to that in the prototype. The theorem also implies that residual stress conditions are the same.

A great body of experience has been developed, particularly at the David Taylor Model Basin, for satisfying these requirements. Because of the difficulty of achieving similitude in every detail, however, some doubt can arise as to the adequacy of model prediction.

Thus, in 1951, the Bureau of Ships undertook a program of hydrostatically testing full scale models, and a 30-ft diam tank was built at the Portsmouth Naval Shipyard specifically for this purpose.[39]

Four tests have been concluded in this tank wherein models were completely instrumented and subjected to hydrostatic pressure that culminated in failure. Results have been compared with predictions from tests of corresponding small scale models, and agreement was sufficiently close as to reinforce confidence in the small scale model technique.[40]

In cases where the fatigue strength of submarine hulls has required study, models are subjected to cyclic variations of service pressure to stimulate a 20-yr. life. Subsequently, the models are pressurized to destruction to determine whether the strength at the end of the submarine's life meets requirements. In the case of fatigue, scale effects in the material properties become vastly more significant than with static loading and, because of the exceedingly high cost of full scale tests and facilities, alternate test procedures are still being sought.

Final verification of submarine strength lies, of course, in performance of the completed structure. While tests to confirm the collapse depth are clearly impracticable, strain measurements are made on the first submarine of each class during the initial "deep dive" to operating depth. Gage locations are selected at areas where strains can be compared with theoretical predictions as well as at those portions of the submarine where strains are expected to be high and which may not have been duplicated in scale models. Anywhere from 200 to 400 such gages are used. Beginning in 1951, techniques were developed to waterproof gages satisfactorily for installation outside the hull. Electrical leads totaling 2 mi may be required to connect these instruments to central switchboxes and automatic recording equipment located inside the sub.

Such dives are conducted by taking initial "zero-load" measurements at periscope depth and then at convenient increments until the test (operating) depth is reached. Data are evaluated at each stage to determine the satisfactory functioning of equipment as well as the linearity and the adequacy of structural performance that would assure safety of continued descent. In general, agreement between results from these dives and predictions from model tests has been good. Rather large discrepancies occasionally exist at specific points of similar structure due largely to local irregularities and to the effects of secondary structures which may be present in the actual submarine and which must often be omitted in the simplified small scale model.

Dynamic Strength

Because naval submarines are designed for combat, it is essential that the hull resist the effect of enemy attack. The reader is sure to recognize that, if the problem of static strength requires the sophistication of analysis just described, the problem of dynamic strength is even more complex. However, consideration of enemy attack does not imply the provision of protective structure as is the case with armor on surface vessels. Moreover, no hull could resist explosive effects of a target-seeking contact weapon. Rather, an evaluation of design is required to assure a uniformity of strength so that no straw alone may "break the camel's back."

In the first instance, toughness of structure represented by high energy-absorption-capacity and low notch sensitivity must be present for the hull to withstand intense impact with only damage and derangement of material, but without lethal hull splitting. Materials and techniques of construction that satisfy this requirement are mandatory. A further concept has evolved, however, that an optimum design for static strength is usually a good design for dynamic strength. A corollary to this axiom is that a selection of geometries which reduce sensitivity to imperfect shape with hydrostatic pressure may, at the same time, improve resistance to damage from dynamic loading.[41] Moreover the elimination of "hard spots" is critically necessary, and results from many explosion tests have emphatically confirmed the need for adequate attention to small details so as to eliminate structural discontinuities.

Another corollary of this concept is that a good design for great depth automatically improves resistance to enemy attack at medium depth.[5]

Minimum Weight Design

Having outlined fundamental principles and mechanisms of hull failure that would permit rational design, it is still necessary that some concept or philosophy be adopted that would guide proportioning of hull structure. In the first instance, the designer seeks maximum strength with minimum weight. However, this still leaves a wide variety of choices of the manner in which dimensions of the submarine are selected. The discussion which follows touches briefly on several different design philosophies, followed by comment on several indexes of merit which the author has proposed for evaluating structural efficiency.

In the first instance, the submarine hull like many other plate and shell structures may fail in any of several different modes so that it is necessary to assure adequacy of strength in all. Twenty years ago, it was proposed that dimensions be chosen so that failure would

occur by interbay buckling. The submarine, it was argued, would then have an opportunity to surface after a warning of imminent rupture based on the appearance of dimples in the hull. Subsequently, it was proposed to proportion structure on the assumption that ψ was limited to 1.0 and that this maximum could be achieved by setting λ = 0.8. More recent concepts have evolved from experience with aircraft structures where the motivation to minimize weight parallels that for submarines. If comprehensive and rational (not empirical) theories, fully corroborated by tests, exist for the prediction of strength in each mode independently, many analysts then approach the minimum weight design by equating the strength in all modes to the required strength (collapse pressure, in the case of a submarine). This author has adopted a similar philosophy in suggesting a "one-hoss-shay" criterion to provide for collapse simultaneously by shell yielding, shell buckling and general instability. It must be emphasized, however, that this concept does not merely assume that strength be equated for yield, shell instability and general instability strengths using theories for perfectly circular cylinders. Rather, it is based on the calculation of strength for all three modes, *including* weakening effects of out-of-roundness. It should be recalled that imperfectly circular shells fail as do perfect shells in the same three appearance modes. Theoretical analysis does not yet seem available to permit this type of approach, particularly on the matter of shell instability mode, and achievement of a delicately proportioned "one-hoss-shay" design is rare. There has thus been recourse to alternate, equally arbitrary, concepts.

Because imperfections appear to weaken structure, steps should be taken to reduce the sensitivity to imperfection. In the first instance, imperfection-induced bending stresses can be moderated by designing for general and shell instability pressures to exceed the specified collapse pressure. With dimensions chosen to elevate instability strength 30–75% above collapse, it can be seen that the last (non-hyphen lined) term in eq 11 is shrunk from objectionably large values. Such a step was suggested by design using a "low-λ"[6] concept by which ring spacing is arbitrarily narrowed to compensate for unknowns in effects of noncircularity—a procedure, incidentally, completely consistent with the "one-hoss shay."

The effect of this "low-λ" approach is to seek failure in the yield mode, because it is less susceptible to weakening effects of out-of-roundness. Under these circumstances, it has been found that the pressure factor ψ greatly exceeds 1.0 and, in fact, has been observed to rise to values as great as 1.9. Such indications alone do not guarantee light weight, because the parameter ψ includes no variables representing frame area which obviously contributes to hull weight.

Another advantage in this approach lies in exploiting the full load-carrying capacity of stiffened cylinders when fashioned of strain-hardening types of materials. The yield criterion mentioned earlier has been found by DeHart to be conservative for aluminum. Closing stiffener spacing induces the shell to accept additional loading, perhaps evoking yielding and residual stresses when unloaded.

A structural efficiency factor for cylindrical pressure hulls has been evolved on the basis of which relative geometries could be compared:[6]

$$E_s = \frac{p_c V}{10^4 W} \qquad (13)$$

The pressure, p_c, represents the collapse depth of the hull; the volume V, corresponds to the volume of water displaced by a single bay of typical pressure hull structure; and the weight, W, represents the material of shell and framing corresponding to a single bay.

It is known, of course, that higher yield strength materials elevate the strength-weight ratio, if yield rather than buckling mode is involved. As a consequence of this, the Navy switched from ordinary carbon steels to high tensile steels around 1943 and then to HY 80 steels in 1951. Expression 13 reflects both this benefit and the benefit of improved geometry. A second criterion was thus proposed in which yield strength of material is not a parameter:[6]

$$\varphi = \frac{pR}{h^1 \sigma_y} \qquad (14)$$

where $h^1 = (A_f + L_f h)/L_f$.
On the basis of this second characteristic, the relative merits of geometry alone can be deduced.

Design for Deep Depth

As noted earlier, the motivation for precision and elegance in design practice reach fruition when designing for great depth where the corresponding hull weight may force unhappy compromises in over-all performance. For many years, a myth persisted that the hull weight associated with greater depth was so unacceptable that no operational requirements were evolved with respect to deeper running and no research or development was undertaken to satisfy these requirements. In 1957, under auspices of the Committee on Undersea

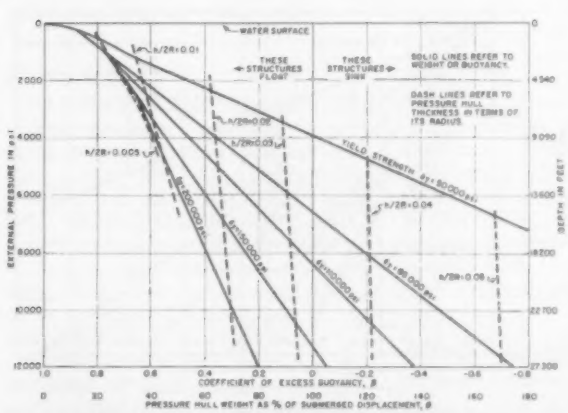

WATER SURFACE
THESE STRUCTURES FLOAT
THESE STRUCTURES SINK
SOLID LINES REFER TO WEIGHT OR BUOYANCY
DASH LINES REFER TO PRESSURE HULL THICKNESS IN TERMS OF ITS RADIUS
YIELD STRENGTH, σ_y = 80,000 psi
EXTERNAL PRESSURE IN psi
DEPTH IN FEET
COEFFICIENT OF EXCESS BUOYANCY, β
PRESSURE HULL WEIGHT AS % OF SUBMERGED DISPLACEMENT, β

Fig. 19—Steel cylinders—weight and thickness for great depth

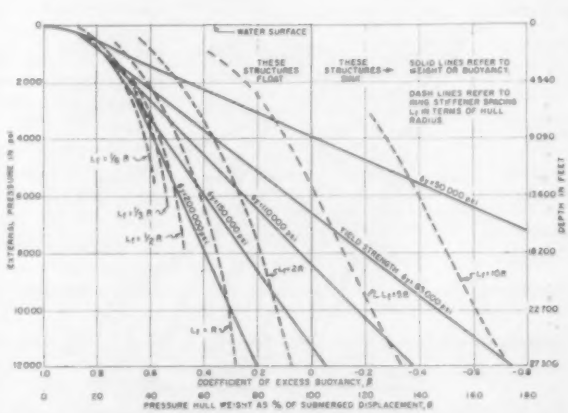

WATER SURFACE
THESE STRUCTURES FLOAT
THESE STRUCTURES SINK
SOLID LINES REFER TO WEIGHT OR BUOYANCY
DASH LINES REFER TO RING STIFFENER SPACING L_f IN TERMS OF HULL RADIUS
YIELD STRENGTH, σ_y = 80,000 psi
EXTERNAL PRESSURE IN psi
DEPTH IN FEET
COEFFICIENT OF EXCESS BUOYANCY, β
PRESSURE HULL WEIGHT AS % OF SUBMERGED DISPLACEMENT, β

Fig. 20—Steel cylinders—stiffener spacing at great depth

Warfare, a special study was undertaken to determine in general terms (and within the boundaries of existing knowledge of materials and geometries) the feasibility of hulls for buoyant submersible vehicles capable of withstanding pressures associated with greater depths. The problem was attacked as follows: Existing theories for thin-shell shallower-diving submarines were extrapolated for thicker cylindrical and spherical sections associated with collapse depths from 2000 to 27,000 ft. Errors in applying thin shell theory to these thicker shells were evaluated and found rather small. Then, for each of the conventional configurations and a number of different materials, calculations were made of the structural efficiency and the excess of buoyancy over hull weight. These results were then reduced to nondimensional forms to render them applicable to any hull size.

A number of unconventional structural configurations were also conceived, including multilayer and sandwich construction as well as ellipsoidal shells, etc. In those few instances where applicable theories existed they were analyzed quantitatively. Finally, those configurations and materials which appeared most promising for deep diving submarines were identified, and recommendations were made for exploiting the results and conducting a program of research to correct the deficiencies in the present state of knowledge.

At the time the National Academy of Sciences study was undertaken, it was (and still is) premature to define theories and principles for the design of deeper diving submarines until more research is completed. Nevertheless, for purposes of feasibility analysis, an idealized cylindrical model was defined, and strength calculations from which dimensions could be established then undertaken. From this definition of hull, it was possible to determine hull weight, and thus what excess of buoyancy remained for machinery and payload that the submarine must carry to operate. In fact, the excess of buoyancy over hull weight was selected as an unambiguous indicator of feasibility. Typical results for cylinders are given by the solid lines in Figures 19–21. Each solid line represents "structural efficiency" for different yield strength steels, in terms of excess of buoyancy over weight. Of course, when the excess of buoyancy drops to zero or becomes negative, the boat sinks. Those that float must demonstrate a reasonable excess. For purposes of comparison, the excess of buoyancy in contemporary ships is about 78%. Under special circumstances, this might reasonably be dropped to 50–60% but the decision of whether to accept more weight devoted to the hull with consequent penalties in other performance depends on whether the "payoff" of increased depth in terms of military advantages compensates for the penalties—a question beyond the scope of this present paper.

Other curves in Figs. 19–21 have been drawn to show the relationships of stiffener size and stiffener area as a percent of total structure to indicate trends in the geometries of deeper-running subs. Among other implications of these curves is the fact that going twice as deep does not necessarily involve a hull that is twice as heavy (because less stiffeners are required to stabilize the thicker plating associated with greater depths). Moreover, the advantages of higher yield materials only gradually appear; at lower depths there may be none. For greater depths, the curves demonstrate the definite advantage of high yield strength.

The cardinal index of material efficiency, however, revealed by the 1958 feasibility studies was the ratio of yield strength to material density. On this basis, existing high strength aluminum alloys were found exceedingly promising for deep diving boats—Fig. 22. Almost immediately, this discovery led to the design of Aluminaut, an oceanographic research vehicle for operation to 15,000 ft.[53] This performance represents a quantum jump in depth capabilities over the relatively shallow limitations of present combat ships, but obviously at the sacrifice of speed and endurance. Sponsored by the Reynolds Metals Co., this 75-ton vehicle will be constructed at Electric Boat Division with plans for operation by the Woods Hole Oceanographic Institution under aegis of the Office of Naval Research.

Because this vehicle is not intended to operate in jeopardy of enemy attack, a bolted and bonded technique of assembly has been deemed satisfactory. In this instance, the joints are not expected to develop the tensile strength of the parent material because under the action of sea pressure the stresses are exclusively compressive. When on the surface in a heavy sea or when lifted out of the water, tensile bending stresses are moderate and safely accommodated. Whether this mode of construction lends itself to application in combat subs remains to be seen. In the meanwhile, other innovations have been proposed by which these nonweldable materials may be effectively employed. Perhaps the most promising is that of sheathed construction in which a high-strength, nonweldable thick shell is contained

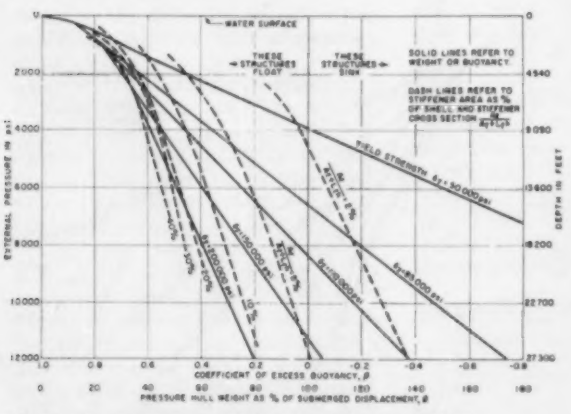

WATER SURFACE
THESE STRUCTURES FLOAT
THESE STRUCTURES SINK
SOLID LINES REFER TO WEIGHT OR BUOYANCY
DASH LINES REFER TO STIFFENER AREA AS % OF SHELL AND STIFFENER CROSS SECTION
EXTERNAL PRESSURE IN psi
DEPTH IN FEET
COEFFICIENT OF EXCESS BUOYANCY, β
PRESSURE HULL WEIGHT AS % OF SUBMERGED DISPLACEMENT, ø

Fig. 21—Steel cylinders—stiffener area for great depth

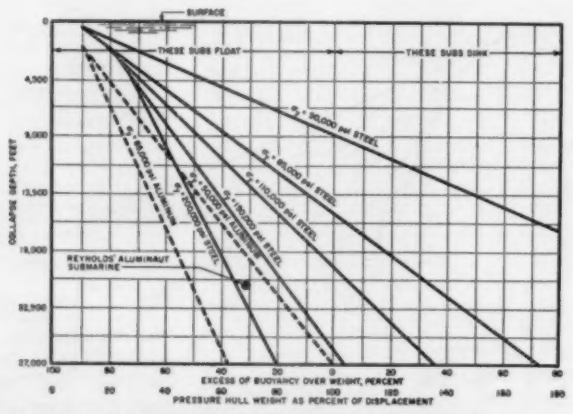


Fig. 22—Weight relationships for great depth showing advantages of aluminum

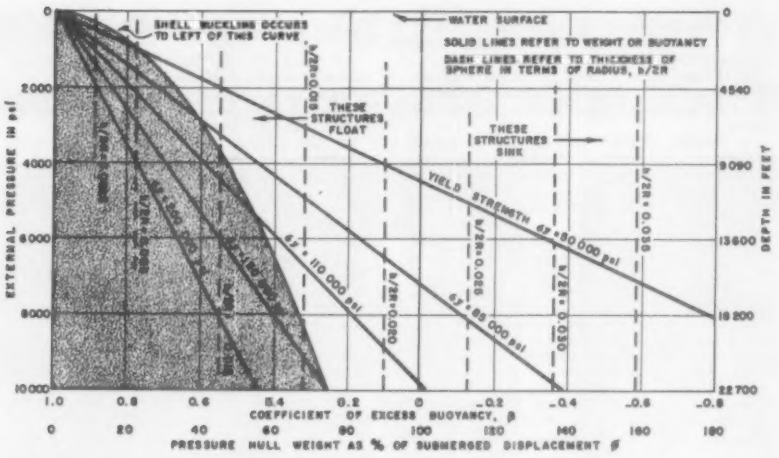

SHELL BUCKLING OCCURS TO LEFT OF THIS CURVE
WATER SURFACE
SOLID LINES REFER TO WEIGHT OR BUOYANCY
DASH LINES REFER TO THICKNESS OF SPHERE IN TERMS OF RADIUS, h/2R
THESE STRUCTURES FLOAT
THESE STRUCTURES SINK
YIELD STRENGTH 67 = 80 000 psi
67 = 110 000 psi
67 = 85 000 psi
EXTERNAL PRESSURE IN psi
DEPTH IN FEET
COEFFICIENT OF EXCESS BUOYANCY, β
PRESSURE HULL WEIGHT AS % OF SUBMERGED DISPLACEMENT ϕ

Fig. 23—Steel spheres—weight-buoyancy-thickness relationships for great depth

within a thin sheath of weldable material. Initial studies by Krenzke and others at the David Taylor Model Basin indicate this mode of construction is satisfactory both under static and dynamic loading. This author suggested a refinement in a recent discussion[49] by specifically using a thick, high strength aluminum hull within a thin weldable aluminum sheath—thus overcoming some objections of electrolytic actions, differences in coefficients of expansion, etc., in otherwise incompatible bimetallic construction. Other materials showing promise for deep diving hulls are fiberglass reinforced plastic and titanium.

While it is apparent that a sufficient excess of buoyancy over weight is derived from cylindrical forms, studies have shown the spherical forms could lighten weight further. Corresponding weight-buoyancy-depth relationships are shown in Fig. 23. While the spherical shell is lighter, the gain is more than offset by poor internal arrangements, difficulty in fabrication and need for hydrodynamic streamlining.

Summary

The structural mechanics of submarine pressure hulls have undergone intensive study and research during the last ten years. Hypotheses on modes of failure have been erected, tested, modified and subjected to computer programming. Such research has not only provided improved precision in design so as to maintain confidence in the use of low safety margins, but it has also provided a generality of application to accommodate unprecedented design problems. Extrapolation of analysis for the design of submarines that could operate 10 to 20 times deeper than their predecessors now appears certain.

The next era in submarine research may require concentration on the materials themselves, including techniques of fabrication, in order that the full potential of operation in the deep ocean may be realized.

Acknowledgments

This summary was prepared while the author was affiliated with Southwest Research Institute, as part of a basic study of deep submergence feasibility sponsored by the Committee on Undersea Warfare of the National Academy of Sciences—National Research Council. In the main, research and development on submarines referred to in the text was accomplished at the David Taylor Model Basin with which the author has had the privilege of association through 1956. Special acknowledgment should be made to the scientific background as well as research climate developed by the author's teacher, Dwight F. Windenburg. In great measure, encouragement of the recent program, especially during its uncertain infancy, is due to the foresight and vigorous Bureau of Ships support of research by Frank W. Dunham, Owen H. Oakley and Commander William E. Hereonemus, USN. For stimulation through discussion with these colleagues and with those whose names find identification as authors of related research papers, the author wishes to express a debt of gratitude.

Nomenclature

A_f = cross-sectional area of ring stiffener.
b = width of rectangular ring stiffener.
d = depth of rectangular ring stiffener.
E = Young's modulus.
E_s = structural efficiency factor, $p_c V/10^4 W$.
F = radial load transmitted from shell to ring stiffener.
h = thickness of cylindrical shell.
I = moment of inertia of cross section of ring stiffener.
L = unsupported length of shell between stiffeners.
L_b = center to center spacing of heavy bulkhead rings.
L_f = center to center spacing of ring stiffeners.
L_s = total length of stiffened cylinder.
P = column load.
p = external hydrostatic pressure.
p_c = collapse pressure.
Q_0 = radial shear transmitted between shell and ring.
R = mean radius of cylindrical shell.
u_0 = initial out-of-roundness in rings or cylinders.
V = volume of cylindrical shell per bay.
W = structural weight of stiffened cylindrical shell per bay.
α = angle of initial tilt of ring stiffeners.
β = $1 - (W/V\Delta)$ coefficient of excess buoyancy.
δ = density of structural plates and shell.
Δ = density of sea water.
ϵ = eccentricity of ring centroid due to tilt. (Also defined as a different parameter in equation 6b.)
λ = slenderness ratio $\lambda = \sqrt[4]{(L/2R)^2/(h/2R)^3}\sqrt{\sigma_y/E}$.
ν = Poisson's ratio.
ϕ = $(W \times 100)/V$, weight as percent submerged deplacement.
ψ = pressure factor, $\psi = p_c R/h\sigma_y$.
σ_y = yield strength of material.

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EUROPEAN WELDING RESEARCH

(*Continued from page 271-s*)

strike being on the tension side. The transition temperature of unnotched specimens with arc strike was about the same as the notch impact transition temperature of a specimen $^3/_8$ in. square 0.079 in. depth and diameter of notch. The harmful effect of arc strikes could be removed by grinding to a depth of not over 0.028 in.

• The fillet weld hot cracking test was preferred to butt joints for hot cracking tests of covered electrodes. Substitution of feldspar and electric furnace ferromanganese for granite and blast furnace ferromanganese in an electrode coating based on titanium concentrate and manganese ore had little effect on cracking.

• An electrode coating containing plastics (no details) has been developed which is insoluble in water. The arc voltage did not change after exposure to the atmosphere for 45 days.

• Single-component electrode coatings were applied to $^5/_{32}$-in. mild steel core by sodium silicate. The single components were Fe_2O_3, MnO_2, TiO_2 and CaF_2. The surface tension of the metal increased from 700 to 1000 dynes/cm in going from Fe_2O_3 to CaF_2 while the number of drops per second decreased from 7.6 to 1.9 and spatter decreased from 30 to 12.5%.

• Cold rolling raised the strength of welds in aluminum to that of base metal.

• A machine for gas welding railroad rails has a contour heating head.

• Sodium-silicate-bonded submerged-arc fluxes were made for hard surfacing at the 200 and 450 Brinell levels. The Mn, Cr, and C contents of the deposits increased as the current was decreased and as the voltage was increased.

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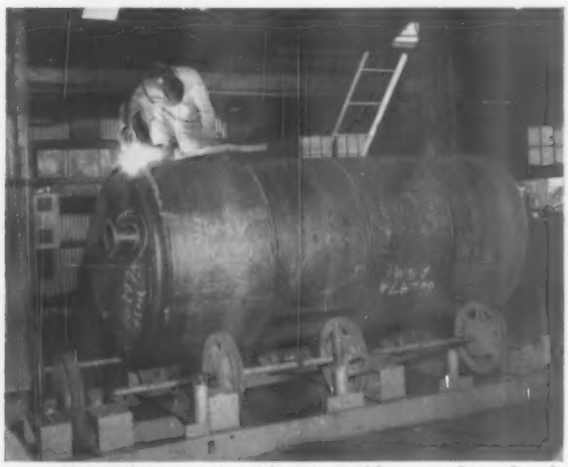

The tank is completed by Mig welding two flanged-and-dished heads to the shell. The heads were formed and spun right in the shop from circles of Everdur-1010 (60⅝" in diameter x .383" thick)—further testimony to the easy workability of Everdur.

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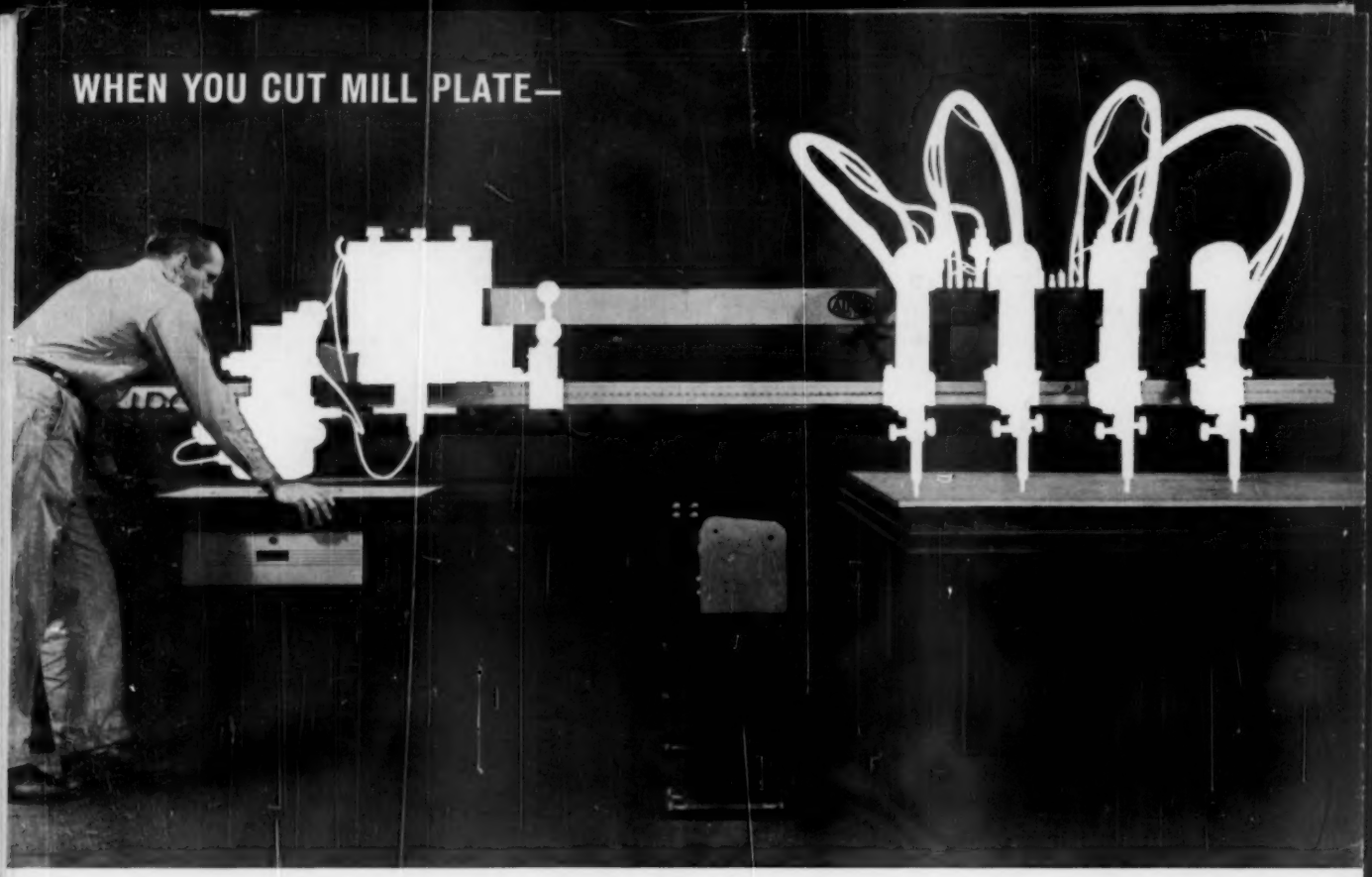

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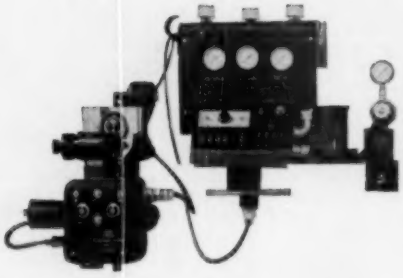

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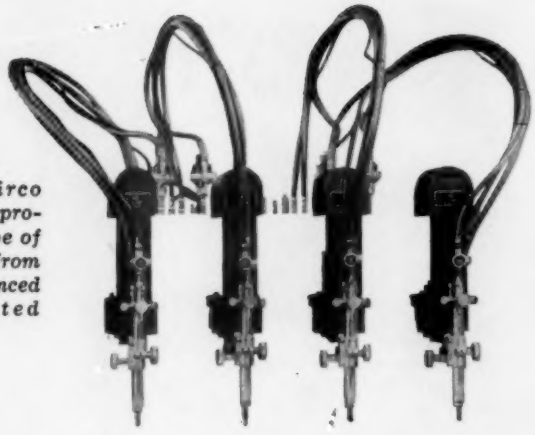

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